JANUARY 2024

M.Sc. in Civil Engineering

HAMZA BARKAD ROBLEH

REPUBLIC OF TÜRKİYE

GAZİANTEP UNIVERSITY

GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES

METEOROLOGICAL DROUGHT ANALYSIS IN KIZILIRMAK BASIN

M.Sc. THESIS

IN

CIVIL ENGINEERING

BY

HAMZA BARKAD ROBLEH

JANUARY 2024

METEOROLOGICAL DROUGHT ANALYSIS IN KIZILIRMAK BASIN

M.Sc. Thesis

in

Civil Engineering

Gaziantep University

Supervisor

Prof. Dr. Mehmet Ishak YUCE

by

Hamza Barkad ROBLEH

January 2024

METEOROLOGICAL DROUGHT ANALYSIS IN KIZILIRMAK BASIN

submitted by **Hamza Barkad ROBLEH** in partial fulfillment of the requirements for the degree of Master of Science in **Civil Engineering, Gaziantep University** is approved by,

Prof. Dr. Çiğdem AYKAÇ
Director of the Graduate School of Natural and Applied Sciences ………...............

Prof. Dr. Nildem TAYŞİ
Head of the Department of Civil Engineering ………...............

Prof. Dr. M. İshak YÜCE
Supervisor, Civil Engineering ………...............
Gaziantep university

Exam Date: 26 January 2024

Examining Committee Members:

Prof. Dr. M. İshak YÜCE
Gaziantep University ………...............

Prof. Dr. Ali AYTEK
Gaziantep Islam Science and Technology University ………...............

Asst. Prof. Gökmen ÖZTÜRKMEN
Gaziantep University ………...............

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

Hamza Barkad ROBLEH

ABSTRACT

METEOROLOGICAL DROUGHT ANALYSIS IN KIZILIRMAK BASIN

ROBLEH, Hamza Barkad
M.Sc. in Civil Engineering
Supervisor: Prof. Dr. Mehmet İshak YÜCE
January 2024
72 pages

Drought, a major phenomenon that has an impact on water resources, viability, sustainability, and the economy, has been one of the most important hydrological concerns. In the literature, it has been classified into 4 groups that are meteorological, agricultural, hydrological and socio-economic. Meteorological drought expresses the precipitation deficits when they are significantly below those recorded normal times. In this study, using Standard Precipitation Index (SPI) and mean monthly precipitation records of 17 stations, a drought monitoring analysis have been done for Kızılırmak Basin, Türkiye, for the time scales of 1, 3, 6, 9, 12, 24-month considering the categories of Severe and Extreme Drought, SED (SPI ≤-1.5) and Severe and Extreme Wet, SEW (SPI ≥1.5). To detect the possible trends in the two categories of all time scales, a developed form of Innovative Trend Analysis (ITA) is performed by adding 2 vertical lines. Also, a traditional Mann-Kendall Test is applied to SPI series. Results have put forth that in all time scales generally dry frequencies are observed as higher than wet frequencies. In addition, mild drought (MD) has higher occurrence percentage than all other drought classes. ITA results have shown that the majority of results for all time scale has shown a trend (89%), the percentage of increasing trend in SEW class is noted as 62.74% and the percentage of decreasing trend in SED class has become 60.78%. Mann-Kendall analysis has shown that the percentages of increasing and decreasing trends in all time scales have been noted as 33% and 67% respectively.

Keywords: Drought, SPI, Mann-Kendall, ITA, Kızılırmak basin.

ÖZET

KIZILIRMAK HAVZASINDAKİ METEOROLOJİK KURAKLIKLARIN ANALİZİ

ROBLEH, Hamza Barkad
Yüksek Lisans Tezi, İnşaat Mühendisliği
Danışman: Prof. Dr. Mehmet İshak YÜCE
Ocak 2024
72 sayfa

Kuraklık, su kaynakları, sürdürülebilirlik ve ekonomi üzerinde etkisi olan önemli bir olgu olup, en önemli hidrolojik endişelerden biri olmuştur. Kuraklık, literatürde meteorolojik, tarımsal, hidrolojik ve sosyo-ekonomik olmak üzere 4 gruba sınıflandırılmıştır. Meteorolojik kuraklık yağışların normal zamanlarda kaydedilen yağışlardan daha az olduğu yağış eksikliklerini ifade eder. Bu çalışmada, 17 istasyonun aylık ortalama yağış kayıtları ve Standart Yağış İndeksi (SPI) kullanılarak, Şiddetli ve Aşırı Kuraklık (SPI $\leq$-1.5) ve Şiddetli ve Aşırı Yağışlılık (SPI $\geq$1.5) durumlarını dikkate alarak Kızılırmak Havzası için 1, 3, 6, 9, 12, 24 aylık zaman ölçekleri için kuraklık analizi yapılmıştır. Tüm zaman ölçeklerinin söz konusu iki kategorisindeki olası eğilimleri tespit etmek için Inovatif Eğilim Analizi'nin (ITA) 2 dikey çizgi eklenerek geliştirilmiş bir formu kullanılmıştır. Ayrıca, SPI serileri için geleneksel Mann-Kendall Testi uygulanmıştır. Sonuçlar, genel olarak tüm zaman ölçeklerinde kuru sıklıkların genellikle yağışlı sıklıklarından yüksek olduğunu ortaya koymuştur. Hafif kuraklığın (MD), diğer tüm kuraklık sınıflarına göre daha yüksek meydana gelme yüzdesine sahip olduğu analiz edilmiştir. ITA sonuçları, tüm zaman ölçekleri için çoğu sonucun bir trend gösterdiğini (%89), Şiddetli ve Aşırı Yaşlık sınıfındaki artış eğiliminin yüzde 62,74 olduğunu ve Şiddetli ve Aşırı Kuraklık sınıfındaki azalış eğiliminin yüzde 60,78 olduğunu göstermiştir. Mann-Kendall analizi, tüm zaman ölçeklerinde artan ve azalan eğilimlerin yüzde 33 ve yüzde 67 olarak belirtildiğini göstermiştir.

Anahtar Kelimeler: Kuraklık, SPI, Mann-Kendall, ITA, Kızılırmak havzas.

’’To my dear family, with love and gratitude’’

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Prof. Dr. Mehmet İshak YÜCE as well as Dr. Musa Esit and Dr. Ibrahim Halil Deger for their guidance and endless support throughout my thesis study. I am thankful for their encouragement and motivation and also their support which without it I would not have graduated. I would like to express my love and gratitude to my family for their support, love and best wishes. Last, but no least, I am thankful to all my friends who have given me motivation and showed me the way to success is not to give up whatever difficulties we are dealing with, especially Dr. Esmail Alshuqari and Eng. Hassan Mahad Hassan.

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

LIST OF SYMBOLS

α	Alfa
β	Beta
Γ	Gamma
σ	Sigma
μ	Mu
λ	Lambda
τ	Tau

LIST OFABBREVIATIONS

SPI	Standardized Precipitation Index
ITA	Innovative Trend Analysis
MK	Mann-Kendall
SRI	Standardized Runoff Index
PNI	Percent of Normal Index
DPI	Discrepancy Precipitation Index
DI	Deciles Index
SPEI	Standardized Precipitation Evapotranspiration Index
SDI	Streamflow Drought Index
ADI	Aggregate Drought Index
RDI	Reconnaissance Drought Index
MGM	Meteoroloji Genel Müdürlüğü
NDMC	National Drought Mitigation Center
IPCC	Intergovernmental Panel on Climate Change
NOAA	National Oceanic and Atmospheric Administration
NCEI	National Centers for Environmental Information
PDF	Probability Density Function
ML	Maximum-Likelihood
CDF	Cumulative Distribution Function
SED	Severe and Extreme Drought
SEW	Severe and Extreme Wet
WMO	World Meteorological Organization
UNESCO	United Nations Educational, Scientific and Cultural Organization
GWP	Global Water Partnership
UNEP	United Nations Environment Programme
IPCC	Intergovernmental Panel on Climate Change
WHO	World Health Organization

CHAPTER I
INTRODUCTION

1.1 Introduction

Global warming is currently one of humanity's most pressing environmental challenges, with the potential to have a wide range of negative impacts. Droughts are one of the most perilous, random and not predictable consequences of global warming. Drought is generally thought to be a climatic phenomenon linked to a prolonged period of precipitation significantly below the usual levels (Olukayode Oladipo, 1985). However, a precise definition of a sustained period is not clearly outlined in scientific literature (Olukayode Oladipo, 1985). For example, in a moist environment where rainfall is typically distributed evenly during the growing season and irrigation is not extensively utilized, a dry period of several weeks in the summer might be considered a drought. Furthermore, when viewed in relation to water usage, drought can be seen as a shortage of food or water rather than merely a lack of precipitation. In such cases, the definition of drought extends beyond meteorology, as the scarcity of food or water depends on how effectively water supplies are managed. Consequently, there is no universally accepted definition of drought. This is because, unlike floods, droughts are not discrete events, and they often result from the intricate interplay of various complex factors with the environment (Olukayode Oladipo, 1985). Adding to the complexity of defining drought is the absence of a distinct starting or ending point (Olukayode Oladipo, 1985). Drought becomes recognizable only after a certain period, and because it can be interrupted by one or more short wet periods, determining its end is often challenging (Olukayode Oladipo, 1985). It is vital to go over some of the key characteristics of this important phenomenon as described in the literature in order to understand its essence. Droughts are intricate phenomena (Shiau and Modarres 2009), characterized as a natural event with detrimental effects on land and resource production systems, causing significant hydrological imbalances due to a substantial decrease in precipitation levels compared to the established normal levels (WMO, 1997), considered the least comprehended catastrophes (Kao and Govindaraju 2010), Frequent occurrences with increasingly detrimental effects (Ullah et al. 2023), with a gradual evolution over long periods of time and exerting widespread impact (Ahmadi and Moradkhani 2019; Sun et al. 2023), acknowledged as the worst and most widespread natural disaster (Zhou et al. 2023). In addition to its characteristics, drought has been categorized into four groups: meteorological, agricultural, hydrological, and socio-economic (Kheyruri et al. 2023; Deger et al. 2023; Yang et al. 2023; Yuce et al. 2023; Niaz et al. 2023). Significantly below average precipitation deficits are referred to as meteorological droughts (Akturk et al. 2022).

Among numerous methods to characterize droughts, indices are commonly used methods. In reviewing the literature, numerous drought indices have been suggested for the identification and anticipation of drought occurrences (WMO & GWP, 2016; Yuce and Esit 2021, Tsakiris, 2007). Typically, various indices are employed for the analysis of meteorological drought, including the Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI), Standardized Anomaly Index (SAI), Palmer Drought Severity Index (PDSI), Self-Calibrated Palmer Drought Severity Index (sc-PDSI), Palmer Z Index, Percent of Normal Precipitation, Aridity Index (AI), Aridity Anomaly Index (AAI), Crop Moisture Index (CMI), China Z Index (CZI), Drought Reconnaissance Index (DRI), Drought Area Index (DAI), Deciles, Effective Drought Index (EDI), NOAA Drought Index (NDI), Reclamation Drought Index (RDI), Rainfall Anomaly Index (RAI), and Weighted Anomaly Standardized Precipitation Index (WASP). These indices play a crucial role in meteorological drought analysis (WMO & GWP, 2016). Nevertheless, the most widely used index is the Standardized Precipitation Index (SPI), as proposed by McKee et al. (1993) and McKee (1995), as emphasized by Akturk et al. (2022). Additionally, the World Meteorological Organization endorses the SPI for monitoring meteorological droughts, as noted by Hayes et al. (2011). Esit and Yuce (2023) have affirmed that the SPI's widespread acceptance worldwide is attributed to its simplicity in determining multiple time scales. The index requires only precipitation as data which can be in the form of daily, weekly or monthly rainfall (WMO & GWP, 2016).

Trend analysis involves the techniques required to elucidate the data behavior. In addition to assessing drought events through indices, understanding the behavior of these events is crucial for effective water resources management and operations

(Simsek 2021). The Mann-Kendall test (Mann 1945; Kendall 1975) stands out as a widely practiced method for trend investigation, as acknowledged by Alam et al. (2023) and employed by various researchers such as Ashraf et al. (2023), Suhana et al. (2023), Dufera et al. (2023), and Thi et al. (2023). Another method for trend detection that has got a significant attention to scientists is the Innovative Trend Analysis (ITA) (Elouissi et al. 2021, Ashraf et al. 2021, Simsek et al. 2022, Alam et al. 2023; Achite et al. 2023; Yuce et al. 2023; Soylu Pekpostalci et al. 2023). Şen (2012, 2017) has developed this method. According to Şen (2012), ITA differs from well-known trend methods in that it does not require considerations such as the independent structure of the time series, normality of distribution, and length of data. Mallick et al. (2021) have asserted that ITA can overcome these limitations effectively.

The Kızılırmak Basin was chosen as the study site in order to deal with a major problem that the region is currently facing and to be beneficial to the region itself (Selcuk Ozturk et al., 2023). According to UNEP, the mediterranean region is warming 20% faster than the global average, which put treats to millions of populations such as water scarcity, social unrest, immigration, conflicts, soil deterioration and agricultural loss. The Mediterranean region is facing adverse effects due to global warming, resulting in changes in precipitation patterns, increased temperatures, and extended periods of drought. Furthermore, as per the IPCC reports, the primary regions in Türkiye most affected by climate change are the Mediterranean, Aegean, Eastern, and Central Anatolia regions (Selcuk Ozturk et al., 2023). It is obvious that the basin is prone to drought. In this context, the outcomes of this investigation are anticipated to be advantageous for the development of drought action plans and the effective management of water resources, benefiting state stakeholders as well.

1.2 Objective of the study

The objective of this study is to conduct a comprehensive assessment of drought in the Kızılırmak basin, Türkiye, utilizing monthly mean precipitation data from 17 stations. This research explores short- and long-term meteorological drought investigation in the basin. We will highlight occurrences and risks of drought in the Kızılırmak Basin, providing valuable insights for strategic water resource planning and drought prevention. We will investigate percentages of occurrences of different drought classes, emphasizing maximum and minimum percentage of occurrence of these classes and examining which parts of the basin that is under influence of these categories. Moreover, we will look into the trend tendencies of drought and wet classes. To achieve this, a) Monthly mean precipitation records across various time intervals were acquired from the General Directorate of Meteorology of Turkey (MGM). b) The time series of drought events were generated using the Standardized Precipitation Index (SPI) for time scales of 1, 3, 6, 9, 12, and 24 months. c) The Mann-Kendall Test and Innovative Trend Analysis (ITA), which involves adding two vertical lines, were applied to the series. The novelty of the study lies in the analysis of drought trends using ITA, presented graphically with the addition of vertical lines at -1.5 and 1.5 points for the Kızılırmak Basin in Türkiye. The findings from this research are anticipated to contribute to the effectiveness of drought action plans and the management of water resources.

1.3 Thesis Layout

This study is composed of six chapters. Chapter 1 is the introduction part. Drought definition is given according to literature review, the importance of ITA and SPI is mentioned, and the importance of this research is addressed. In chapter 2, a detailed drought definition is given, different types of droughts are explained, drought impacts are presented, and studies done by different researchers using various methods are presented as well as their importance. In chapter 3, the information of study area is given, and the properties of selected stations is presented in table. In chapter 4, the importance of selected methods in this research is explained as well as the calculation procedure of the methods is detailed. In chapter 5, the results are presented. The outcomes of this study are highlighted with graphics and tables. Chapter 6 is the conclusion of this study and the contribution of this study to stakeholder.

CHAPTER II

LITERATURE REVIEW

2.1 Drought definition, responsible factors, types and consequences.

In this part, we will review some important drought definitions given in literature review, main factors leading to droughts, different types of drought and drought serious repercussions.

2.1.1 Drought definition and previous study

It is usually difficult to apply definitions of drought from one place to another since they are distinctive to that region, taking into consideration differences in meteorological conditions and involving a variety of physical, biological, and socio-economic elements. Drought as a complicated calamity, lacks a universal definition, changes gradually and has unobvious effects (Wilhite, 1992). Furthermore, it is a commonplace occurrence observed in nearly every climate worldwide, including those with high precipitation. The absence of rainfall for a short period does not necessarily indicate the onset of drought, and conversely, substantial rainfall in a region facing drought does not signify the end of the drought. Consequently, establishing a universally accepted definition of drought proves to be a challenging endeavor. Nevertheless, some commonly accepted definitions of drought include the following: drought is a gradual onset natural disaster, often associated with a reduction in rainfall within a specific area over a period of time (Mishra and Singh, 2010); it is characterized as a shortage of precipitation over a prolonged period, typically a season or more, leading to water scarcity (National Integrated Drought Information System); in the International Convention to Combat Desertification, it is described as a natural event that negatively impacts land and resource production systems, causing significant hydrological disparities due to precipitation falling considerably below recorded normal levels (WMO, 1997). Additionally, identifying the commencement and end of a drought is frequently challenging (UNESCO, 2005). Drought becomes discernible only after a specific duration, and the end of drought is often hard to ascertain due to potential interruptions by one or more brief wet periods.

In contrast to other natural disasters like floods and cyclones, the effects of a drought accrue gradually over time and may persist even after the drought ends (Wilhite, 1992). When compared to other natural hazards, droughts have the potential to cause the greatest harm to human life and property under a range of climatic and environmental conditions (Sırdaş and Şen, 2003). The anticipated exacerbation of drought conditions due to climate change poses challenges for the management of reservoirs, aquifers, and other water infrastructure. It is imperative for individuals and communities affected by drought to prepare for and adapt to a drier climate (Natural Drought Mitigation Center, USA). Understanding the factors leading to drought is crucial.

Global water consumption is predicted to increase as a result of fast population expansion and globalization (Zhang et al. 2011). On the other hand, predictions based on global climate models suggest that either more evaporation or less precipitation causes more droughts (Dai 2011; Trenberth 2011). Thus, although previous droughts might be one factor that contributes in the limited availability of water resources, other factors including inadequate management and increased water demand due to population expansion should also be considered (Nafarzadegan et al., 2012).

Prior studies in the literature have demonstrated substantial interest among researchers worldwide, as well as in Türkiye, in the evaluation and investigation of drought. For example, globally, Bhunia et al. (2020) conducted a meteorological drought study in the Purulia, Bankura, and Midnapore districts of India using SPI. They assessed the trend of the SPI series through the Mann-Kendall test. Additionally, Achite et al. (2023) undertook a study on meteorological and hydrological drought in the Wadi Ouahrane Basin, Algeria, employing SPI and the Standardized Runoff Index (SRI) for various time scales (1, 3, 6, 9, 12, 24 months). Subsequently, they subjected these series to analysis using Theil-Sen estimator, the Mann–Kendall test, the Modified Mann–Kendall test, and the Innovative Trend Analysis. Regarding Türkiye, Dabanlı et al. (2017) examined droughts across Türkiye by employing SPI and data from 250 station records. Gumus and Algin (2017) conducted a study on meteorological and hydrological drought analysis for Seyhan and Ceyhan Basins, utilizing Streamflow Drought Index (SDI) and SPI for time scales of 3, 6, and 12 months. Yuce and Esit

(2021) conducted a drought monitoring study for the Ceyhan Basin, employing 10 indices, including SPI, across time scales of 3, 6, 9, and 12 months. Katipoğlu et al. (2021) performed a spatio-temporal assessment of meteorological and hydrological droughts in the Euphrates Basin, Türkiye, utilizing five indices, including SPI, for time scales of 1, 3, and 12 months, Topçu et al. (2022) carried out meteorological drought analyses for the Mediterranean, Seyhan, Ceyhan, and Asi Basins with the help of Aggregate Drought Index (ADI), a meteorological drought investigation for the Black Sea Region was conducted by Simsek et al. (2023), employing SPI and Reconnaissance Drought Index (RDI) methods at 3, 6, and 12-month time scales. Specially for Kızılırmak basin, Selcuk Ozturk et al. (2023) have performed a meteorological and hydrological drought analysis of the Kızılırmak basin using Standardized precipitation index (SPI) and Streamflow Drought Index (SDI), Akturk et al. (2022) has conducted meteorological drought analysis in the Kızılırmak River Basin using Standardized precipitation index (SPI) and monthly data precipitation of 22 stations for the 1960-2017, Akturk et al. (2022) conducted a study on meteorological drought analysis utilizing SPI for time scales of 1, 3, 6, 12, and 24 months, a hydrological drought characteristics assessment has been performed by Deger et al. (2023) using SDI for time scales of 1, 3, 6, 9, 12, and 24 months, and trends were investigated by ITA. In research published in the literature, drought analysis in the Kızılırmak Basin—the subject study in this research—has also gained attention of many researchers (Bacanli et al., 2011; Yildiz 2014; Oguzturk et al., 2015; Arslan et al., 2016; Beden et al., 2020; Çıtakoglu and Minarecioglu, 2021; Akturk et al., 2022). Global warming is a major issue that the region is currently facing, so research on meteorological drought analysis in the Kızılırmak basin was chosen. Furthermore, a small amount of research has been published on the Kızılırmak basin's meteorological drought analysis. Kızılırmak basin, being as the second-largest basin in Türkiye, its meteorological research and trend analysis should help state holders with drought mitigation and improved water management resources.

2.1.2 Drought Responsible factors

The ocean-atmosphere system, anomalies in sea surface temperature, high soil temperature during drought and an increase in fine particles in the air, high albedo in arid areas, solar-weather relationship, and monsoon mechanism and its disruptions are the factors attributed to the onset of drought (Nagarajan, 2010).

2.1.2.1 Rainfall

Drought is primarily triggered by a reduced frequency of precipitation, with the most pronounced signals occurring during seasons when anticipated substantial precipitation does not occur. The distinction between normal and insufficient precipitation often hinges on the contribution of precipitation from storms. Essentially, the absence of a few substantial storms during a season can be adequate to instigate drought (Moradi et al., 2011; Karl et al., 1987). While the total precipitation amount varies annually, the average amount remains relatively constant over several years in most regions. Typically, desert regions receive less than three inches of precipitation per year, whereas coastal areas experience an average annual precipitation of over 1.50 inches. Even if the total yearly rainfall is roughly average, shortages can occur during critical periods when moisture is essential for plant growth. In such instances, the absence or minimal rainfall can lead to the death of plants (Nagarajan, 2010).

2.1.2.2 Temperature

Elevated surface air temperatures are typically linked to multi-year droughts. The amount of moisture present is directly correlated with land surface temperatures in the summer (Guillemot et al., 1996). Temperatures are kept lower and there is typically more precipitation when the soils are wet because a large portion of the heat from incoming sunshine is used to evaporate water. On the other hand, little or no water is available for evaporation if the soil is dry. As a result, the surface can only get warmer from the incoming sunlight, which will make the weather hotter and drier and start the process that leads to drought (Sun, C. & Ma, Y., 2015).

2.1.2.3 Hemispheric nature

A global, or at the very least hemispheric, climatic view on drought takes into account interactions between the atmosphere and its land and ocean borders. It is not possible to limit the causes of a drought to the atmosphere above the impacted area. We refer to daily variations in precipitation, temperature, wind, and other variables as weather, not climate. Even in theory, weather cannot be predicted for durations more than roughly two weeks (Thiele et al., 1985).

2.1.2.4 Wind velocity and evapo-transpiration

Evapo-transpiration is the most important part of the hydrologic budget. Seasonally and regionally, it changes. It changes based on the wind and weather. It keeps draining the small amounts of water that are still present in soil, lakes, and streams. Through evapo-transpiration, surface water outflow, groundwater outflow, and consumptive consumption of the rainfall, respectively, about 67%, 29%, 2%, and 2% are communicated back (Nagarajan, 2010).

2.1.2.5 Human actions

Last but not least, human activities can contribute to the onset of drought, exacerbating conditions through practices such as over-farming, excessive irrigation, and erosion, which adversely affect the land's capacity to absorb and retain water.

2.1.3 Different types of droughts

Drought can be categorized into four types based on the parameters: (1) Meteorological Drought. (2) Agricultural Drought. (3) Hydrological Drought. (4) Socioeconomic Drought. These drought categories are shown in Figure **2.1** and Figure **2.2**. To sum up, according to Heim et al. (2022) “A deficiency in precipitation is known as a meteorological drought; a deficit in soil moisture is known as an agricultural drought; a shortfall of stream flow is known as a hydrological drought; and a shortage of any economic products impacted by the drought process is known as a socioeconomic drought.”

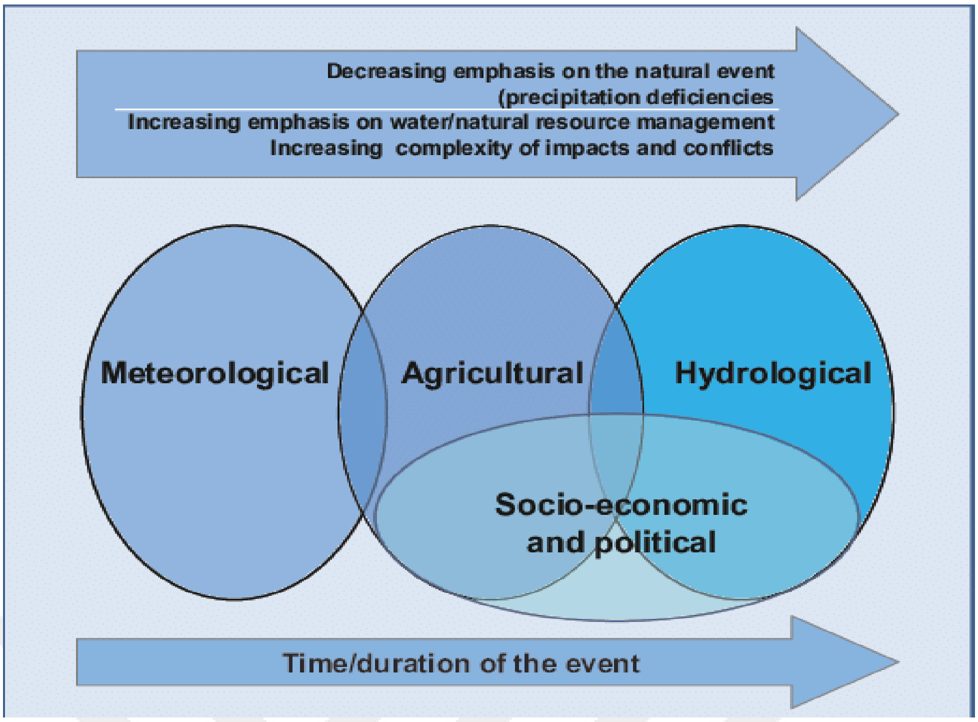


Figure 2. 1. Interrelationships among the four types of droughts. (Drought monitoring and early warning: concepts, progress and future challenges, World Meteorological Organization)

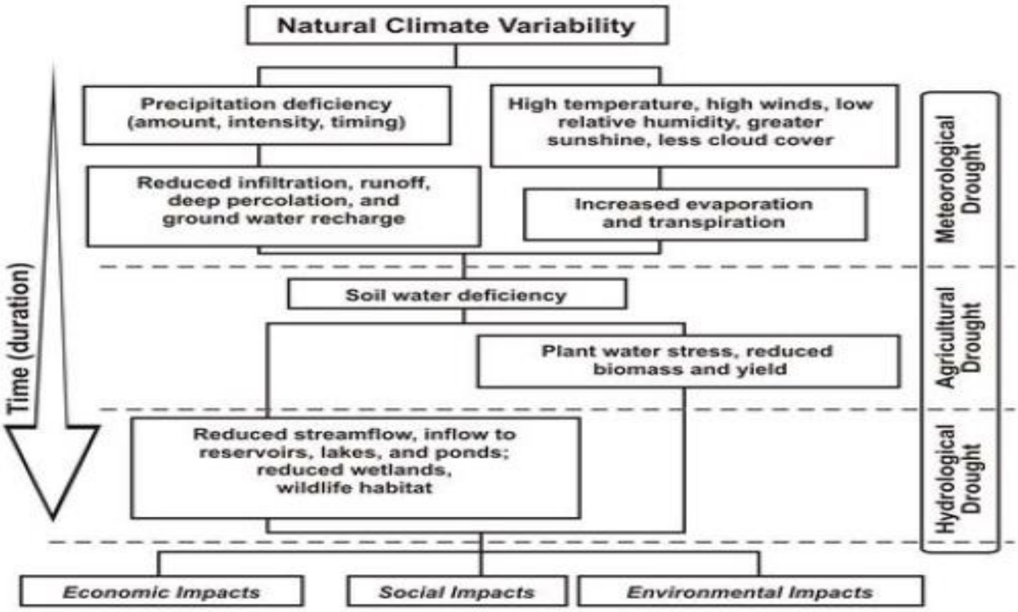


Figure 2. 2. Relationship between meteorological, agricultural and hydrological drought (Chaisson, 2012).

2.1.3.1 Meteorological drought

The duration of the dry period and the degree of aridity are the main characteristics of meteorological drought. It indicates a precipitation deficit compared to a predetermined threshold, impacted by precipitation variability that is closely linked to detailed geophysical and oceanic processes. In other words, significantly below average precipitation deficits are referred to as meteorological droughts (Akturk et al. 2022). In recent years, meteorological droughts have become more frequent, and the impact of climate change is anticipated to further escalate their duration and severity, as indicated by the statement, " It seems expected that the duration and severity of the drought will worsen."(Castano, A. 2013). It is crucial to recognize that the definition of meteorological drought must be region-specific due to the highly variable atmospheric conditions leading to precipitation deficiencies across different regions (National Drought Mitigation Center NDMC).

2.1.3.2 Agricultural drought

It's a lack of soil moisture, which reduces the amount of moisture available to plants. Because it is directly linked to crop failure, soil moisture drought is also known as agricultural drought (Corti et al., 2009; Van der Molen et al., 2011)**.** Agricultural drought connects diverse aspects of meteorological drought to agricultural effects, focusing on precipitation shortages, discrepancies between actual and Immanent evapotranspiration, reservoir levels or groundwater reduction, and soil water deficiencies, and so on. The climate, the biological structure of the plant, its stage of growth, and the physical and biological qualities of the soil all influence how much water a plant requests (National Drought Mitigation Center NDMC). Stress brought on by low soil moisture can reduce plant populations and crop yields.

2.1.3.3 Hydrological drought

The effects of periods of precipitation deficits on surface or subsurface availability are linked to hydrological drought. In other words, the consequences of precipitation shortages on surface and groundwater supplies, such as streams, reservoirs, lakes, and aquifers, are referred to as hydrological drought. Besides, a lack of "normal" water availability in rivers, lakes, and groundwater levels across a large area is referred to as a "hydrological drought". It is distinguished by low groundwater and surface water (lakes, rivers) flows and levels (Nafarzadegan et al., 2012; Castano, A. 2013).

Persistent below-average precipitation over an extended period is manifested by a reduction in both surface and subsurface water levels, with significant variations depending on different water usage (Nagarajan.R., 2010). However, the primary cause of droughts lies in insufficient rainfall. The assessment of the frequency and intensity of hydrological drought often employs watershed or river basin scales. Hydrological system components like soil moisture, streamflow, and groundwater and reservoir levels take longer to exhibit precipitation deficits, as highlighted by the National Drought Mitigation Center (NDMC). Following months of meteorological drought, hydrological drought becomes apparent through diminished streamflow, lower reservoir and lake levels, and a reduction in wetlands and wildlife habitat.

2.1.3.4 Socioeconomic drought

Socio-economic drought relates the supply and request of some economic good with meteorological, agricultural and hydrological drought. It differs from the other forms of droughts in that its occurrence is determined by the time and spatial processes of supply and demand. This makes it difficult to distinguish or define it. Numerous economic goods, such as water, pasture, food grains, and hydroelectric power, are impacted by climatic conditions when they are stored. Water availability varies naturally throughout the year, with some years having an abundance and others not having enough to meet the requirements of people and the environment. It is connected to the effects of the three categories listed above. It can be used to describe the consequences of drought on the environment and human health, as well as the inability of water supply systems to meet demand (Chopra, 2006). Socio-economic drought occurs when demand for water exceeds supply due to a weather-related water shortage. For example, demand for a particular food crop may exceed supply owing to agricultural drought, or demand for electricity may surpass supply because water shortages reduce the hydroelectric power production load. A relationship between the meteorological, agricultural and hydrological droughts can be illustrated from Fig. 2.2.

2.1.4 Impact of climate change on droughts

Climate change is recognized as a significant threat in the twenty-first century. Analyzing instrumental data over the past 157 years indicates a global rise in surface temperatures, marked by noticeable regional variations. The warming trend in the twentieth century is divided into two phases: a moderate increase from the 1910s to the 1940s (0.35°C) and a more pronounced rise from the 1970s to the present (0.55°C) (IPCC, 2007). The past decade (2014–2023) has seen the occurrence of the 10 warmest years in the last 174-year record (1850-2023) (*Annual 2023 Global Climate Report | National Centers for Environmental Information, NCEI*). Specific regions are experiencing increased aridity due to climate change. For instance, the Southwestern United States has witnessed a decline in annual precipitation since the early 20th century, and this trend is expected to persist ("Drought and Climate Change | Center for Climate and Energy Solutions", 2021). When it comes to Türkiye, in accordance with the IPCC reports, the key regions in Turkey significantly impacted by climate change are the Mediterranean, Aegean, Eastern, and Central Anatolia regions (Selcuk Ozturk et al., 2023).

Elevated temperatures lead to higher evaporation rates, reducing surface water and desiccating soils and vegetation. Consequently, low-precipitation periods become drier in warmer temperatures. Additionally, a diminished snowpack poses a significant challenge, as many water management systems depend on spring snowmelt. The reduction of snow coverage increases surface temperatures because snow serves as a reflective surface, exacerbating drought conditions. Some climate models suggest that warming contributes to increased precipitation variability, resulting in more frequent periods of both excessive precipitation and drought. During drought years, this necessitates additional water storage, alongside an elevated risk of floods and dam failure during periods of extreme precipitation.

2.1.5 Drought impacts

Drought does not only affect humans; plants and animals are also vulnerable during extremely dry periods. Drought influences the distribution of water over a vast geographic area, temporarily lowering the quantity of moisture accessible to the local water cycle. Also, drought has non-structural consequences and affects a larger geographical area than other natural hazards. Droughts have significant economic, social, and environmental consequences. They have a negative impact on agriculture, the environment, and health, resulting in severe socioeconomic consequences (Dai, 2013; Mishra & Singh, 2011; Rahman & Lateh, 2017). There are various ways in which droughts differ from other natural disasters. When compared to other natural dangers, droughts cause the greatest number of casualties. For instance, 40% of the world's population suffers from water scarcity, and by 2030, up to 700 million people could face forced migration due to drought (WHO, 2023). In addition, the damage produced by droughts is more widespread than that of other natural disasters. Finally, because droughts lower land productivity, which lowers the amount of plant that absorbs carbon dioxide, they can increase atmospheric carbon dioxide levels.

2.1.5.1 Water supply impact of drought

Droughts are characterized by a scarcity of accessible water. In times of drought, communities may face limited access to water for essential activities such as drinking, cooking, cleaning, plant irrigation, and for broader purposes like agriculture, transportation, and power generation. The consequences of droughts may include increased water expenses, or, in severe cases, the depletion of vital water sources, as witnessed by a rural California community in 2021. **(**Drought and Climate Change | Center for Climate and Energy Solutions, 2021). Snowpack can be unusually low or missing during droughts because the freezing precipitation required to produce the snowpack was diminished or lacking during the wet season. Because of the absence of water stored as snowpack during the winter months, the amount of water available for the rest of the year may be reduced. Drought reduces the quantity of runoff that fills our rivers and streams. Water flowing over the ground is referred to as runoff. It is the water that remains after some of the water from precipitation and snowmelt has vaporized or been immersed into the ground to fill groundwater and nourish trees and plants. When there is a prolonged period of low precipitation, the land’s surface is reached by less water. This water is divided between soil infiltration, evaporation, and transpiration, leaving a smaller amount of water to flow over the surface. That limits the amount of water accessible to rivers, lakes, and reservoirs, as well as for the plants, animals, and humans who rely on them. Pollutants can be concentrated because of reduced flows in rivers and streams, jeopardizing the quality of water available for drinking and recreational.

2.1.5.2 Agriculture impact of drought

Droughts affect both livestock and crops, including staples like corn, soybeans, and wheat. In the 2012 drought, the United States Department of Agriculture declared a natural disaster in 2,245 counties, encompassing 71% of the country. Simultaneously, key breadbasket regions worldwide faced drought in 2012, contributing to fluctuations in food prices. The rise in costs in countries already grappling with food shortages has the potential to trigger civil instability, migration, and famine (Drought and Climate Change, 2021).

2.1.5.3 Erosion impact of drought

The lack of moisture, that binds soil particles together, causes them to become loose when the earth dries out. This causes strong winds to erode the soil and remove its top layers. This erosion can deplete the soil of nutrients and minerals, preventing plant growth. It can also trigger dust storms, which are harmful to the health of animals and people in the impacted areas.

2.1.5.4 Wildlife and flooding impact of drought

Droughts and the fires that occur from them can cause sudden floods, which can trigger an unanticipated consequence for the land. Long-term drought can cause soils to harden and consolidate, making it difficult for rainwater to sink into the ground. When the rains eventually arrive in the region, they will wash off the crusty soil and spill across the countryside, causing sudden bouts of flooding with no warning and catastrophic erosion and debris flows. Flooding that causes debris flows, silt, and ashes may block a canal that residents use to get their drinking water.

2.1.5.5 Economic impacts of drought

The water level of 88 dams that are now used to produce electricity was at 44.6% in January 2014, according to data from the State Water Works. There are 18 drainage basins where these dams are situated, and in 14 of those basins, the water level was lower than in 2013 (Türkeş, M. & Yıldız, D. 2014). Thus, drought threatens hydroelectric power supply and indirectly can adversely influence economic. Another example; as of October 8, 2021, there have been eighteen climate disaster events that have affected the United States, with damages exceeding $1 billion in each case. These drought-related repercussions can all be very expensive for people, companies, and governments. The United States had nine droughts between 2011 and 2020, with each causing damage of at least $1 billion **(2020 U.S. billion-dollar weather and climate disasters in historical context | NOAA Climate.gov, 2021).** Since 1980 to 2021, 28 droughts occurred in United states. It represents 9.8% of total billion-dollar disasters hit in United states for 42years. The economic losses related to drought catastrophes are enormous. It is the third costly disaster incurring in United States see Table **2.1**.

Accounting for just 9.8% of the total number of events, droughts have caused more than 13% of the total damages attributed to billion-dollar weather and climate disasters since 1980. Droughts are the second major in terms of cost per disaster after cyclone which are 9.2 and 19.2 billion dollars respectively (Smith, 2022).

Table 2. 1. The breakdown, by hazard type, of the 285-billion-dollar weather and climate disasters assessed since 1980. Screenshot from the NOAA NCEI Billion-dollar Disaster.

Disaster type	Events	Percent frequency	Total costs	Percent of total costs	Cost/event	Death/year
Drought	28	9.8%	$ 258.9B	13.8%	$ 9.2B	95
Flooding	33	11.6%	$ 151.08B	8.0%	$ 4.6B	15
Freeze	9	3.2%	$ 30.7B	1.6%	$ 3.4B	4
Severe storm	128	44.9%	$ 286.3B	15.3%	$ 2.2B	43
Tropical cyclone	52	18.2%	$ 997.38B	53.1%	$ 19.2B	161
wildfire	18	6.3%	$ 102.3B	5.5%	$ 5.7B	10
Winter storm	17	6.0%	$ 0.18B	2.7%	$ 2.9B	26
All disasters	285	100.0%	$ 1,876.6B	100.0%	$ 6.6B	353

2.1.6 Drought monitoring and trend analysis

Drought monitoring is very crucial because they are a natural occurrence in any climate regime on Earth, including deserts and rainforests. Drought ranks among the more economically burdensome natural hazards on an annual basis, with significant and widespread impacts affecting various economic sectors and populations simultaneously. Drought-affected areas generally have greater danger footprints than other types of hazards, which are normally limited to floodplains, coastal regions, storm tracks, or fault zones. Monitoring droughts is particularly well-suited due to their slow onset, allowing ample time to observe alterations in precipitation, temperature, and the overall condition of surface water and groundwater supplies in a given region. Drought indicators or indices are commonly employed to aid in monitoring, and these tools vary depending on the region and season. One of the widely used indicators is Standardized precipitation index. It was developed by Tom McKee, Nolan Doesken, and John Kleist at the Colorado Climatic Center in 1993. SPI is capable of being computed across various time scales, allowing for the assessment of water deficits of varying durations. Its design aims to demonstrate the possibility of concurrently experiencing wet conditions at one or more time scales while encountering dry conditions at another time scale. To compute the index for each time scale, an appropriate probability density function (PDF) must be fitted to the frequency distribution of the accumulated precipitation. The literature presents various PDFs, including the Gamma distribution, exponential distribution, lognormal distribution, Weibull distribution, Normal distribution, and logistic distribution.

The Mann-Kendall (MK) Test is a non-parametric test commonly employed in the analysis of climatic data trends, focusing on the sequences rather than the numerical values of the data (Burn & Elnur, 2002). It holds widespread application in hydrological and climatological studies for the identification of trends in time series data. Renowned for its suitability in discerning monotonic trends in persistent datasets, the MK test is considered superior to other parametric tests (Mann, 1945). This test stands out as one of the most frequently utilized non-parametric methods in the literature, with a substantial presence in trend analysis studies (Buffoni et al., 1999; Déry et al., 2005; Kumar et al., 2010; Mondal et al., 2012).

The Innovative Trend Analysis (ITA) method is a graphical approach to detect trend in time series. One key characteristic that distinguishes ITA is its capability to identify non-monotonic trends (Sadık & Alashan, 2023). ITA stands out as an innovative method for trend analysis that can discern trends at different levels within a given time series, encompassing both lows and highs (Emmanuel et al., 2022). According to Fatma et al. (2022), ITA has been successfully applied to various climatic parameters, demonstrating its effectiveness in detecting trends across a broader spectrum of parameters. Furthermore, as highlighted by Michael et al. (2022), ITA is not influenced by constraints such as data length, distribution type, or serial correlation, rendering it a more flexible and reliable analytical method.

CHAPTER III

STUDY AREA

3.1 Location and Extent of Study Area

Kızılırmak Basin, with a surface area of 82 221 km^2 (~10.49% of Türkiye's surface area), is located between 32.80° and 38.35° East longitudes and 35° and 41.75° North latitudes (Akturk et al. 2022). The longest river flowing entirely within Turkey is Kızılırmak river. It has a total length of 1355 km. Following the Tuna, Dinyeper, and Dinyester Rivers, Kızılırmak is the 4th largest river that flows into the Black Sea (Çakmak, B., 2002; Bacanlı et al., 2012). In addition, it is one of Turkey's 25 basins. Turkey basins boundaries are given in Figure **3.1**. The basin area covers a wide area which includes all parts of Sivas, Kayseri, Sinop, Samsun, Kastamonu, Aksaray, Niğde, Tokat, Yozgat, Amasya, Erzincan, Ankara, Konya, Çankırı, Nevşehir, Kırşehir, Çorum, Kırıkkale provinces of Türkiye. According to Khorrami et al. (2023a, b), the average annual temperature and precipitation are approximately 461 mm and 10.5 °C, respectively. Due to the extensive coverage of the basin, it encompasses diverse climate types (Republic of Türkiye Ministry of Agriculture and Forestry, 2019). The interior part experiences a semi-arid climate, while the coastline sections closest to the Black Sea experience a humid to semi-humid climate. The river is home to several dams, including the Boyabat, Altınkaya, and Derbent. The climate of the basin primarily matches that of Central Anatolia's continental climate, with a tiny area influenced by the Black Sea climate. It reaches its highest level of the water regime in April, while it flows in the lowest water level between February and July (B. Ercan, 2016; Yüce, M. İ, 2015)**.** Snow is the most common form of precipitation in the winter, and it stays on the ground for a long period. Kızılırmak river has tremendous amount of water storage area. With an annual flow volume of 6,48 billion m^3, the Kızılırmak river accounts for 3.5 percent of Turkey's water potential (Selcuk Ozturk et al., 2023). Rain and snow are the sources of the Kızılırmak River, which has an intermittent regime. With its total drainage surface area, 624103 hectares are irrigated. The Kızılırmak River, with a drainage area of 78646 km², has an average flow value of 185 $m^3/_s$ and carries 831 million m^3 of water into the Black Sea annually (Oğuztürk. G., 2010; Yanmaz 2013; Çakmak, B., 2002; Bacanlı et al., 2012). The name of kızılırmak was inspired from the color of red clay sediments in the river bed in the Kızıldağ district of Sivas. The river rises in Sivas, in the eastern province of Central Anatolia, on the southern slopes of the Kızıldağ area. İmranlı, Hirfanlı, Derbent, Boyabat, Kesikköprü, Obruk, Dutludere, Altınkaya, Kapulukaya, Yamula, Çermikler, Buğra, Sarıoğlan, Bayramhacı, and Kargı are the names of the fifteen dams on the Kızılırmak River. The majority of the Kızılırmak river basin, which is situated in the center of the Kızılırmak basin, is one of Ankara's primary water supplies. This route runs from the Hirfanlı Dam in Ankara's south to the Kalecik district's north east. Hydroelectric Power Plants are located in Hirfanlı, Kesikköprü, and Kapulukaya Dams. When fully operated, the Kızılırmak water source can supply up to 500 million m^3 of water per year to Ankara (Johnson, L. E., 2009).

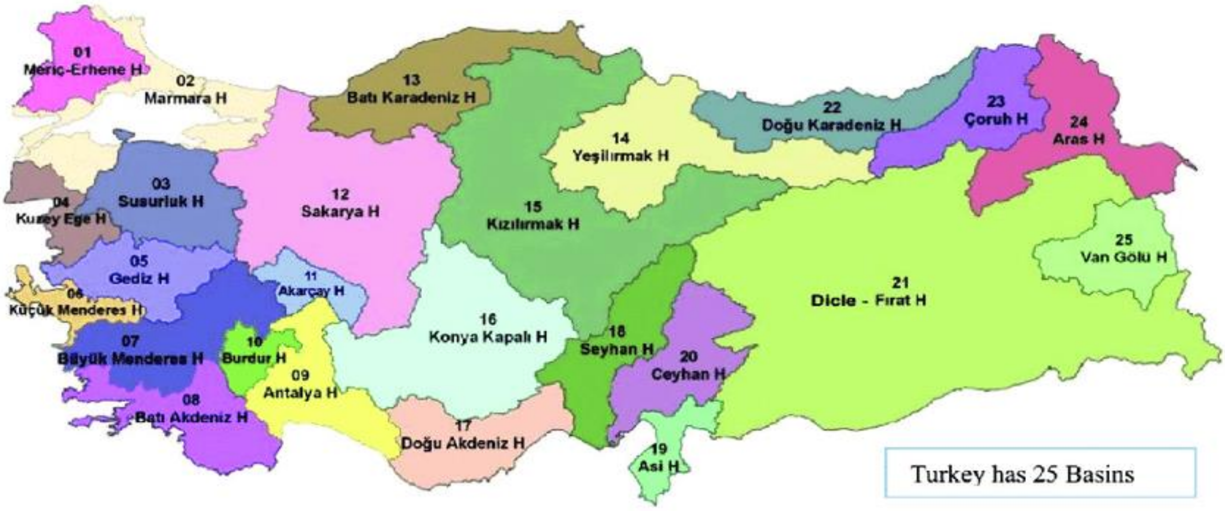


Figure 3. 1. Basin-based precipitation potential of Turkey (Santos et al. 2016).

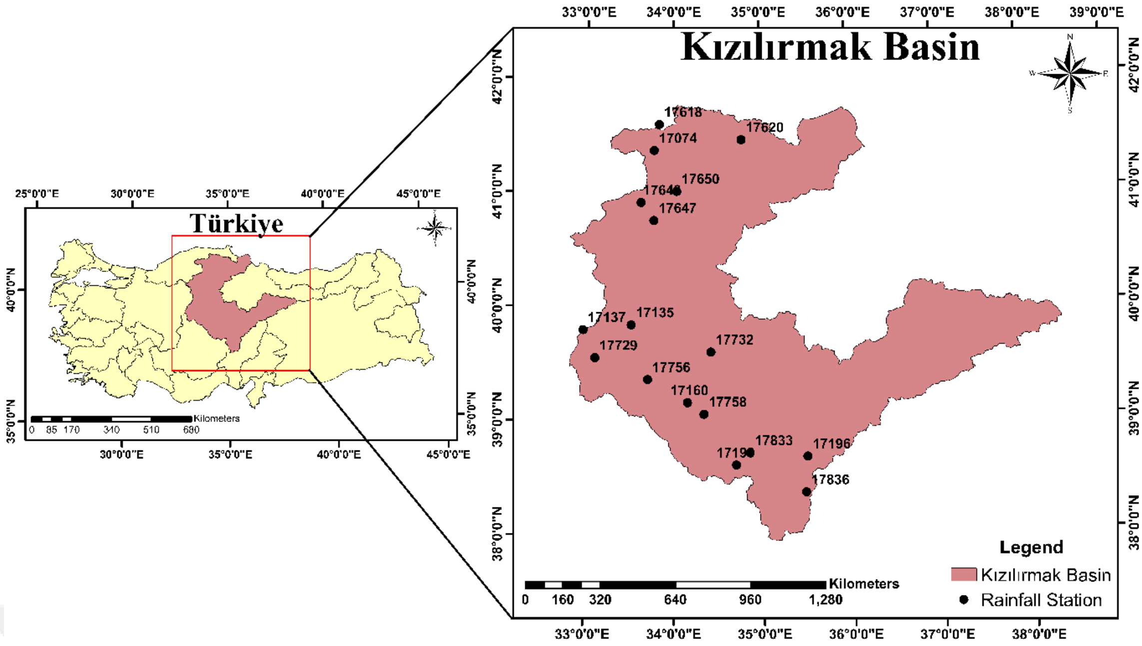


Figure 3. 2. Illustration of Kızılırmak Basin and selected rainfall stations

Table 3. 1. Properties and locations of selected stations

Station	*Station Name*	*Latitude*	*Longitude*	*Elevation (m)*	*Data Interval*	*Max. Rainfall (mm)*	*Average Rainfall (mm)*
17074	Kastamonu	41.371	33.775	800	1930-2021	278.7	40.1
17135	Kırıkkale	39.843	33.518	751	1963-2021	172.7	32.2
17137	Elmadağ	39.798	32.971	1796	2005-2021	257.8	39.8
17160	Kırşehir	39.163	34.156	1007	1939-2021	161.4	32.3
17193	Nevşehir	38.616	34.702	1260	1959-2021	148.8	34.9
17196	Kayseri	38.687	35.500	1094	1939-2021	164.7	32.3
17618	Devrekanı	41.599	33.834	1050	1977-2021	199.0	45.0
17620	Boyabat	41.463	34.785	350	2005-2021	141.2	32.6
17647	Yapraklı	40.758	33.772	1253	2005-2021	152.6	37.2
17648	Ilgaz	40.915	33.625	885	1969-2021	216.6	39.5
17650	Tosya	41.013	34.036	870	1959-2021	171.7	39.5
17729	Bala	39.554	33.108	1248	2005-2021	128.6	29.7
17732	Çiçekdağı	39.606	34.423	900	1971-2021	171.1	29.0
17756	Kaman	39.365	33.706	1075	1966-2021	253.6	38.6
17758	Mucur	39.061	34.341	1097	2005-2021	165.2	30.3
17833	Avanos	38.722	34.856	950	1986-2021	115.7	25.2
17836	Develi	38.374	35.479	1200	1965-2021	159.6	30.6

3.2 Input Data

The data of the precipitation and the locations of statıons are obtained from General Directorate of Meteorology (Meteoroloji Genel Müdürlüğü). 17 rainfall observation stations with records of monthly rainfall data from 1930 to 2021 (record period of minimum 17 years and maximum 91 years). The names and yearly flow data of precipitation stations located on the Kızılırmak Basin are shown in Table **3.1**, and their locations have been shown in Figure **3.2.**

CHAPTER IV

METHODS AND METHODOLOGY

4.1 Standardized Precipitation Index

The development of SPI was initiated by McKee et al. (1993) and McKee (1995). According to Suhana et al. (2023), the SPI only needs monthly precipitation data, making it simple to employ. Because of its simplicity and consistency, the Standardized Precipitation Index (SPI) is used to compute possible drought events. In another words, the SPI is used for estimating wet or dry condition based on precipitation variable. The SPI can be determined along a variety of time span, and it can be used to predict drought and quantify its severity. Quantifying of drought using SPI remains consistent regardless of place or time. The following processes are included in the computational technique for calculating SPI. To begin with, the precipitation aggregated throughout the time scale of interest is fitted with a suitable probability density function (PDF). The second step is to convert each PDF into a normalized normal probability distribution. A gamma distribution is used to fit the precipitation data for the various time scales prior to the SPI computation. SPI-1, SPI-3, SPI-6, SPI-9, SPI-12 and SPI-24 are adapted in this study knowing that drought and its socioeconomic influence progress at a longer temporal scale.

4.1.1 Calculation procedure for SPI

McKee et al. (1993) and Edwards and McKee (1997) detailed the methodology for calculating the Standardized Precipitation Index (SPI) to examine deviations in precipitation from normal conditions. This approach has been widely applied in various studies (Vicente-Serrano 2006; Vicente-Serrano et al. 2010). SPI computation involves utilizing long-term precipitation data specific to a particular location and time period, with a preference for periods exceeding 30 years (WMO & GWP, 2016). Monthly precipitation sums are aggregated over different timescales (1, 3, 6, 9, 12, 18, and 24 months, etc.). To illustrate, for a 3-month timescale, the precipitation accumulation from month j-2 to month j is summed and attributed to month j, excluding the data time series of the first two months at this scale. The normalization process begins by fitting an appropriate probability density function to the long-term time series of aggregated precipitation. The cumulative distribution is then computed using the fitted function, and the data points are transformed into standardized normal variates. This procedure is repeated for all required timescales. In this study, Equation 1 is utilized to calculate the probability distribution function of the gamma distribution.

The probability density function of the gamma distribution is defined as:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}}\, for\ x > 0 \quad (4.1)$$

Where the gamma function is $\Gamma(\alpha)$, the shape parameter is $\alpha > 0$, the scale parameter is β>0, and the amount of precipitation is $x > 0$. A more thorough explanation of the gamma distribution may be found in **Guttman (1999) and Lyod-Huges and Saunders (2002).** α and β are estimated from the sample data in order to fit the distribution parameters. They can be calculated as follows using Thom's (1958) ML approximation:

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \quad (4.2)$$

$$\beta = \bar{x}/\alpha \quad (4.3)$$

Where $\bar{x}$ is mean precipitation and **A** is given by:

$$A = \ln(\bar{x}) - n^{-1} \sum \ln(x) \quad (4.4)$$

In certain circumstances, Wilks (1995) proposes an iterative procedure for more accurate estimation of α and β. For a specific month and time scale, the cumulative probability G(x) of an observed precipitation amount is defined as:

$$G(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \int_0^x x^{\alpha} e^{-x/\beta} dx. \quad (4.5)$$

Letting $t = x/\beta$, we reduce the expression to the following function, called the incomplete gamma function:

$$G(x) = \frac{1}{\Gamma(\alpha)} \int_0^x t^{\alpha-1} e^{-1} dt. \ (4.6)$$

The gamma distribution is not defined for **x=0**, and, the probability of zero precipitation **q=P(x=x)** being positive, the cumulative probability becomes:

$$H(x) = q + (1-q)G(x). \ (4.7)$$

Where G(x) displays the cumulative distribution for the chosen month and time scale, and q denotes the probability of zero. It is possible to calculate q from q=m/n if m is displayed as the number of zeros (Thom 1966). Following these computations, H(x) is transformed into the standard normal variable Z, which reflects the SPI value as provided by Equation 4.8 and has a mean of 0 and a variance of 1.

$$SPI = \frac{X_{ij} - \bar{X}_{im}}{\sigma} \ (4.8)$$

Where X_{ij} represent the total monthly precipitation, $\bar{X}_{im}$ and σ denote the mean and standard deviation of precipitation determined from monthly time series (Yuce and Esit 2021). Then, the SPI values for a given month and the specified time scale are linked to a drought class based on their numerical values, following the drought classifications outlined in Table **4.1**.

Table 4. 1. Categorization of drought utilizing SPI Index

SPI Values	Dry/Wet Classification
≥ 2	Extremely Wet
1.50 ~ 1.99	Very Wet
1.00 ~ 1.49	Moderately Wet
0.99 ~ 0	Normal
0 ~ -0.99	Mild Dry
-1.00 ~ -1.49	Moderately Dry
-1.50 ~ -1.99	Severe Dry
≤ - 2	Extreme Dry

4.1.2 Interpretation of SPI

The SPI, often known as the z score, is the number of standard deviations that an event deviates from the mean. As a result, the 3-month SPI value compares accumulated rainfall over that particular 3-month period to the mean of total rainfall with the same annual period across the whole research period. This is true for any n-month SPI value, where n is not only the time scale but also the number of months of accumulation. High positive numbers for rainfall belong to wet sequences, while high negative values refer to dry periods. Short time scales of 3 months or less may be significant for agricultural applications when evaluating drought (negative SPI), however long time scales of up to several years are more significant in water-supply management (Guttman 1998). Soil moisture conditions, for instance, react to short-term variations in precipitation. Whereas, extended precipitation anomalies manifest in groundwater levels, streamflow, and reservoir storage. The literature has offered a number of classifications of dryness and wetness events depending on the SPI. Table **4.1** illustrates this point (Lloyd-Hughes and Saunders 2002)**.**

4.2 Innovative Trend Analysis

Proposed by Şen (2012), ITA has been utilized due to its simplicity and efficiency (Elouissi et al. 2021; Yuce et al. 2023). Şen was the first to introduce the ITA method (Sen, Z., 2012)**.** In contrast to the MK test or other techniques, the ITA has the benefit of not requiring any assumptions (serial correlation, non-normality, sample number, and so on). The rainfall trends for the maximum monthly, seasonal, and annual time series were analyzed using this method (Mann, 1945). Furthermore, researchers can examine trends graphically thanks to ITA. As stated by Şen (2012) and Esit (2022), to apply this method to a dataset: i) split the data into two equal parts that need to be ranged in ascending order; ii) plot the first part on the x- and second-axes; iii) draw a 1:1 line (45^0) that is not a trend line, as shown in Figure **4.1**. Figure **4.1.a** illustrates that a trend is decreasing when a point is below the 1:1 line and increasing when a point is above the 1:1 line. Since ITA offers the opportunity to assess trends graphically, a novel form of ITA has been created by appending two vertical lines to the combinations of the Severe and Extreme Drought classes (SED) at (SPI ≤-1.5) and the Severe and Extreme Wet classes (SEW) at (SPI ≥1.5), as shown in Figure **4.1.b**. The information about monotonic and non-monotonic situations of trend behaviors of dry and wet classes is also obtained by dividing the ITA graph by specific lines.

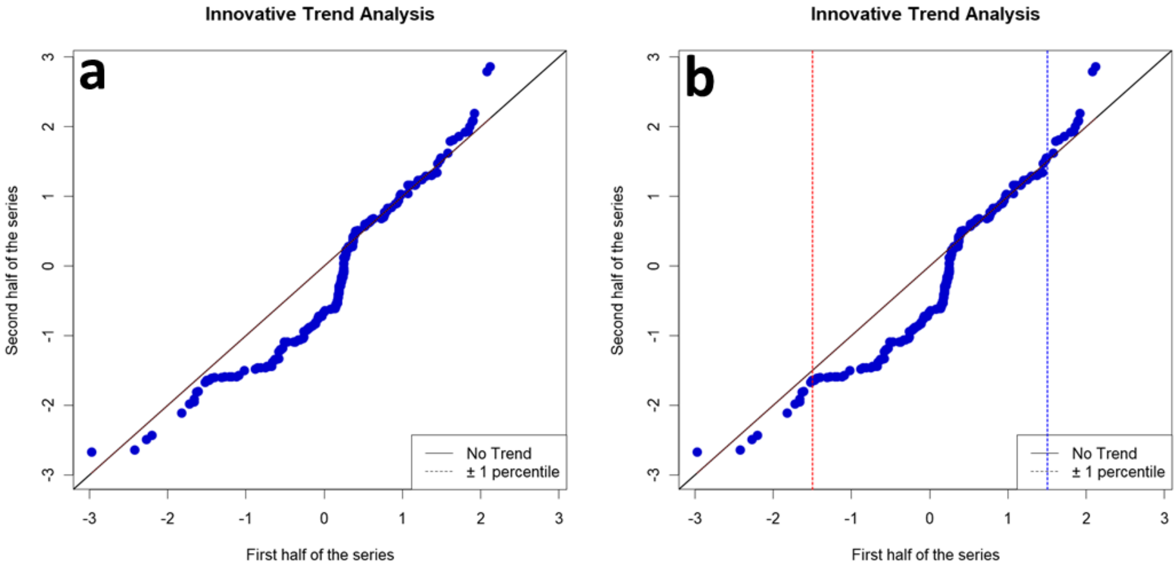


Figure 4. 1. Graphical representation of a) ITA by (Şen 2012) and b) Developed ITA.

4.3 Mann-Kendall Test

As a rank based non parametric test (Mann 1945; Kendall 1975; Ashraf et al. 2023), applying Mann-Kendall Test is popular in the analysis of hydrological and meteorological data (Das and Bhattacharya 2018; Rahman et al. 2017, 2016; Das et al. 2020d). The Mann-Kendal test is the most widely performed to analyze trends for diverse climatological and hydrological data since it less susceptible to missing data and data need not conform to any specific distribution (Mann, 1945)**.**

The presence of a monotonic tendency in a chronological series of a variable is detected using this test. Three kinds of information can be mainly obtained from this technique:

- The Kendall Tau, also known as the Kendall rank correlation coefficient, is a measurement of the slope's monotony. Kendall's Tau is a number that ranges from -1 to 1. The increasing or decreasing trend is related to positive or negative value of the Kendall Tau respectively.
- The Sen slope, which calculates the total slope of time series. The median of all the slopes determined between each pair of points in the series represents this slope.
- The significance, which represents the threshold for which the hypothesis that there is no trend is accepted. If the p-value is less than 0.05, the trend is significant statistically.

4.3.1 Calculation of the Mann-Kendall Statistic (S)

The test statistic (S) of the series $x_1, x_2, x_3 \dots, and\ x_n$ is calculated by using the following formula (Mann 1945; Kendall 1975):

$x_1, x_2 \ldots\ldots x_n$ denotes n data points where the data point at time j is represented by x_j. Next, we get the Mann-Kendall statistic (S) (Mann 1945; Kendall 1975):

$$S = \sum_{K=1}^{n-1} \sum_{j=k+1}^{n} sign\left(x_j - x_k\right) \text{ (4.1)}$$

The trend test is conducted on a time series denoted as x_k,, where k is ranked from 1 to n-1, and x_j , which is ranked from j = k+1 to n, with n representing the total number of data points. In this context, x_j and x_k correspond to the data points at times j and k, respectively.

$$sign\left(x_j - x_k\right) = \begin{Bmatrix} 1\ if\ \left(x_j - x_k\right) > 0 \\ 0\ if\ \left(x_j - x_k\right) = 0 \\ -1\ if\ \left(x_j - x_k\right) < 0 \end{Bmatrix} \text{ (4.2)}$$

The variance statistics is given as:

$$Var\ (S) = \frac{n(n-1)(2n+5) - \sum_{j=1}^{g} \left(t_j - 1\right)(2t_j + 5)}{18} \text{ (4.3)}$$

where g signifies the tied groups' number and t_j signifies the extent of jth tied number.

The Kandall's τ (tau) formula is given as follows:

$$\tau = \frac{S}{B} \text{ (4.4)}$$

$$B = \sqrt{\frac{1}{2} n(n-1) - \frac{1}{2} \sum_{j=1}^{g} t_j \left(t_j - 1\right)} * \sqrt{\frac{1}{2} n(n-1)} \text{ (4.5)}$$

When n > 10, the standardized test measurement Z is developed by calculating the estimation of (S) and VAR(S) as follows (Gilbert 1987).

$$Z = \begin{Bmatrix} \frac{S-1}{\sqrt{Var(S)}}, if\ S > 0 \\ 0, if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, if\ S < 0 \end{Bmatrix} \text{ (4.6)}$$

Generally, positive and negative values of the Z statistic indicate increasing and decreasing trends in the time series, respectively. The null hypothesis (H0) asserts the absence of trends, while the alternative hypothesis (HA) implies trends in the chosen time series (Pearson and Hartley, 1966).

CHAPTER V

RESULTS

In order to evaluate meteorological drought in Kızılırmak basin, SPI values for the different times scales (1, 3, 6, 9, 12 and 24) are assessed and trend analysis are performed on SPI-values through the application of the ITA and Mann-Kendall approaches. For ITA graphical analysis, two categories are determined: severe and extreme wet (SEW) and severe and extreme dry (SED) categories. SEW category is represented by SPI≥1.5 whereas SED category is represented by SPI≤-1.5. Numerical inspection is employed to detect trend type by Mann-Kendall method.

5.1 SPI results

SPI values are obtained for 1-, 3-, 6-, 9-, 12 and 24-time scales for meteorological drought analysis of Kızılırmak basin. Percentages of frequencies are determined by:

$f = \frac{n}{N}$ where n is the number of months in each category and N represents total months (See Appendix 1).

Figure **5.1** shows the comparison between the two categories using SPI-1, (N=826 years*12months/year=9912 months; 100%). It is obvious that the number of months with dry conditions (707 months or 7.1%) is higher than those with wet conditions (573 months or 5.8%) The difference between the two categories in percentage is 1.3%. For dry situations, frequencies (the number of months) fluctuate between a minimum of 11 months (station 17758) and a maximum of 77 months (station 17074). In contrast, the number of months showing wet conditions are between 9 months (station 17729) and 68 months (station 17196).

Using SPI-3-time scale shown in Figure **5.1**, which the first two months for each station are not counted so the total frequency (total number of months for 17 stations) is 9878 months (N=9912 - 2*17=9878 months; 100%), the months representing severe or extreme dry situations (699 months or 7.1%) are still higher than those showing severe or extreme wet conditions (564 months or 5.7%). Interestingly, the difference between the two conditions is strongly closer to SPI-1 results (1.4% and 1.3% respectively). The number of dry months outperforms to those of wet months except for stations: 17137 (12 dry months against 15 wet months), 17196 (55 dry months against 64 wet months) and 17647 (12 dry months against 14 wet months). The quantity of dry months varies between a minimum of 12 months (stations 17137, 17647 and 17758) and a maximum of 73 months (station 17160) whereas for wet conditions SPI-3 frequency ranges between 3 and 64 months (station 17620 and 17196) respectively.

Using SPI-6, the percentage dissimilarity between dry and wet frequencies remains slightly the same as SPI-1 and SPI-3. The number of months with severe or extremely wet conditions (553 months or 5.6%) are smaller than those with severe or extreme dry conditions (670 months or 6.8%). All stations indicated dry conditions (dry frequencies are more than wet frequencies), except for stations: 17647 (11 against 12 wet months), 17648 (30 against 37 wet months or 4.2% against 6.3%) and 17729 (9 against 10 wet months). Over the basin, the minimum and maximum number of dry months has been observed as 9 and 76 months respectively while wet has been noted with 4 months as minimum and 58 months as maximum.

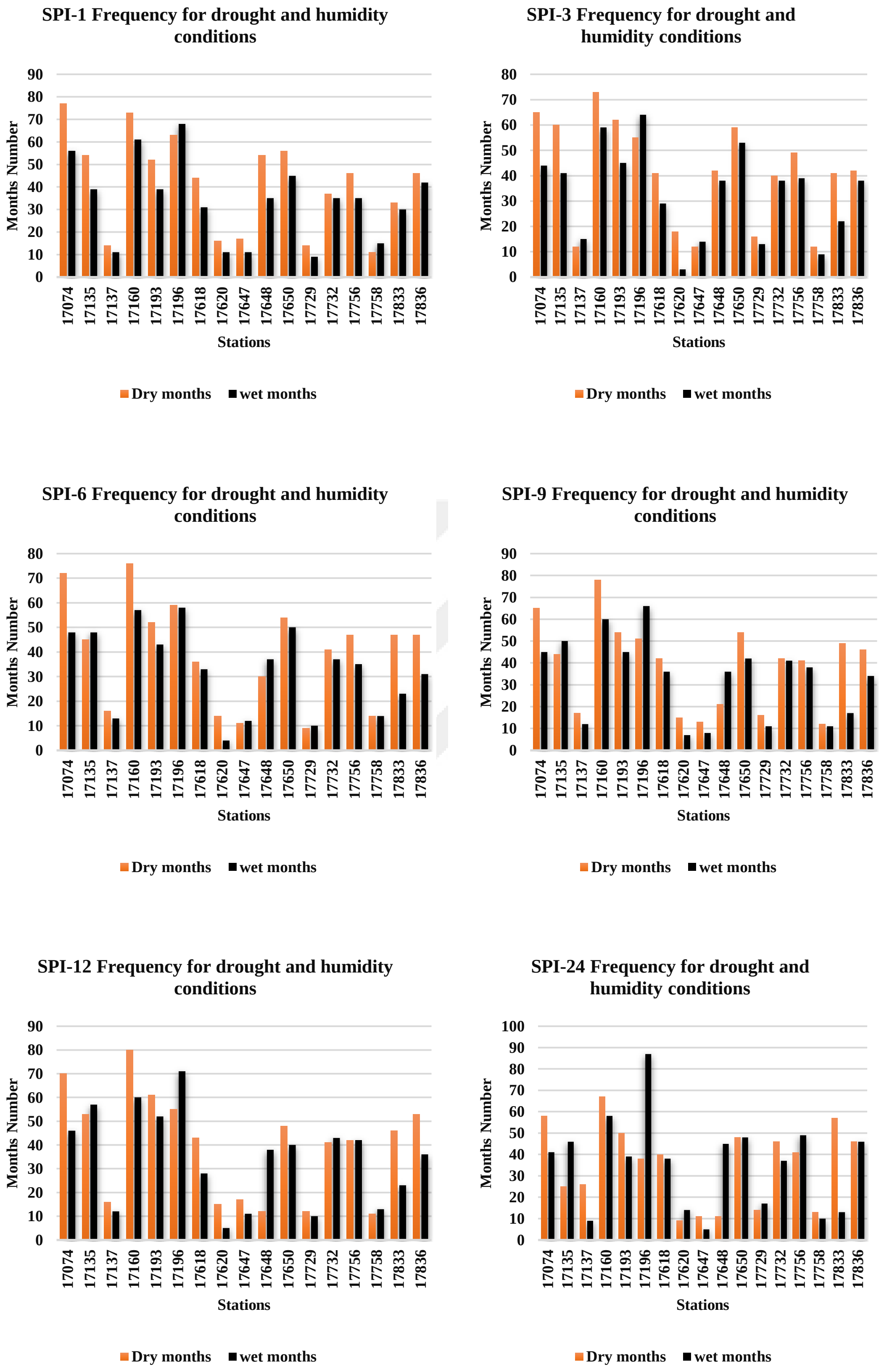
Dry and wet conditions for SPI-9 values, the eight months for each station are not counted so the total frequency is 9824 months (N=9912 -8*17=9824 months; 100%). The difference, in percentage, between categories of dry frequencies (660 months or 6.7%) and categories of wet frequencies (559 months or 5.7%), becomes decreasing (1.0%). Consequently, wet conditions start to increase. It is obvious that from this scale the establishment of balance between the categories has begun. In this time scale, the dry months have been detected with 12 months as minimum and with 78 months as maximum. The wet months have been seen as minimum with 7 months and 66 months as maximum.

In the long-term scale (SPI-12), the frequency (total number of month) is 9725 months (N=9912 -11*17=9725 months). The difference between dry categories and wet categories continues to decrease and it becomes 0.90%. Indeed, the number of wet months start to rise rapidly than dry months compared to the results of SPI-9 (587 months or 6.0% against 675 months or 6.9% respectively). Also, dry months have been ranged as 11-80 months while for wet months the range has been noted as 5-60 months.

The 24-months SPI (Figure 3) showed a different result than those 1,3,6 and 9 SPI values. The dry and wet categories are getting significantly close together. Amazingly, the difference between the categories reaches zero (0,02%). In fact, the number of months showing severe or extreme wet and dry conditions gets too close together (602 against 600 months, respectively). In this time scale the minimum and maximum of dry months have been obtained as 9 and 67 months respectively and the wet months have been detected as minimum 5 months and as maximum 87 months.

SPI can be used as an indicator for immediate effects such decreased soil moisture, snowfall, and flow in smaller creeks when it is computed for shorter accumulation periods for example, 1 to 3 months. Furthermore, the 6-month SPI and 9-month SPI are semi-annual and medium-term scale respectively. They can be utilized as a predictor of agricultural drought. A wide indirect indicator of water resource management is the 12-month SPI (Caloiero 2018). Not only those but also, SPI can be utilized as a sign of decreased reservoir and groundwater recharge when it is computed over longer accumulation periods (such as 12 to 48 months). 12 and 24 month have an impact on how water supplies/reserves are handled**.**

The Kızılırmak basin has been suffering from a severe and intense drought since 1930, according to an analysis of SPIs ranging from one to nine months-time scale. It is obvious that there has been a nine-month-long meteorological drought. It affects plants and can take the shape of agriculture. For long-term time scale, a balance between dry and rainy episodes is formed, so the basin is unaffected by the yearly drought SPI-12. The frequencies of the dry episodes generally outweigh the wet ones.


SPI-1 Frequency for drought and humidity conditions

SPI-3 Frequency for drought and humidity conditions

SPI-6 Frequency for drought and humidity conditions

SPI-9 Frequency for drought and humidity conditions

SPI-12 Frequency for drought and humidity conditions

SPI-24 Frequency for drought and humidity conditions

Figure 5. 1. SPI frequencies for drought and wet conditions

The occurrence of drought categories has been investigated as following classes: Mild Drought (MD), Moderate Drought (MOD), Severe drought (SD) and extreme drought (ED) and wet categories for all (SPI≥0).

- To track drought conditions in the Kızılırmak Basin, the computed SPI values are displayed in Table **5.1** for stations 17074, 17135, 17137 and 17160. The results for all other stations have been presented in appendix 4.
- According to Table **5.1** and Appendix **D**, wet category has higher percentages than all other drought classes for all time scale (1, 3, 6, 9, 12 and 24 months). Furthermore, among all drought classes, MD dominates all other drought categories for all time scale.
- For majority cases, it is evident that the percentage occurrence of MOD is higher than SD and ED with 92 cases out of 102 cases (90%) for all time scale and all stations.
- Table **5.2** displays percentage of minimum and maximum occurrences of drought and wet classes. According to Table **5.2**, minimum and maximum percentage of MOD is higher than SD and ED except for 24-month time scale. In contrast, minimum percentage of SD is higher than minimum percentage of ED except for 6-month and 24- month while maximum percentage of ED is higher than maximum percentage of SD except for 1-month and 3- month time scale.
- The stations with the highest and lowest percentages of MD and Wet categories have been included in the same Table, as the Wet and Mild Drought (MD) classes have the largest rates. As it is clear in the Table **5.2**, the minimum percentages for Wet and MD is, 38.1% and 17.6%, and the maximum percentage is, 63.0% and 50.2%, respectively.
- According to the same Table, the minimum percentage of MD (3 out of 6-time scale) and maximum percentage of Wet (4 out of 6-time scale) have been obtained from station 17833, whereas, the maximum percentage of MD (3 out of 6-time scale) and minimum percentage of Wet (3 out of 6-time scale) has been obtained from station 17648. These stations are located at south and north-west of basin, respectively.

Table 5. 1. Percentage of drought occurrence and wet classifications according to SPI for stations a) 17074, b) 17135, c) 17137 and d) 17160.

a

Dry/wet Classification	SPI Class	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24
MD	(-0.99, 0)	33.0	32.9	34.7	34.5	37.0	36.1
MOD	(-1.49, 1)	8.4	10.5	9.2	11.3	9.9	11.9
SD	(-1.99, -1.5)	3.5	4.4	5.0	4.2	4.9	4.6
ED	≤-2	3.7	2.4	2.9	3.2	3.3	3.6
Wet	≥0	51.4	49.7	48.1	46.7	44.8	43.7

b

Dry/wet Classification	SPI Class	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24
MD	(-0.99, 0)	28.7	28.1	32.5	34.6	35.2	32.2
MOD	(-1.49, 1)	7.9	7.9	9.5	9.0	7.6	14.3
SD	(-1.99, -1.5)	5.1	5.5	4.1	3.8	6.2	2.1
ED	≤-2	2.8	3.7	3.2	3.5	3.1	4.8
Wet	≥0	55.5	54.8	50.7	49.0	47.9	46.6

c

Dry/wet Classification	SPI Class	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24
MD	(-0.99, 0)	27.9	32.4	31.9	24.5	17.6	17.6
MOD	(-1.49, 1)	10.3	11.8	9.3	9.3	11.8	5.4
SD	(-1.99, -1.5)	5.4	3.4	5.9	7.4	6.9	12.7
ED	≤-2	1.5	3.4	4.4	5.4	6.4	11.8
Wet	≥0	54.9	49.0	48.5	53.4	57.4	52.5

d

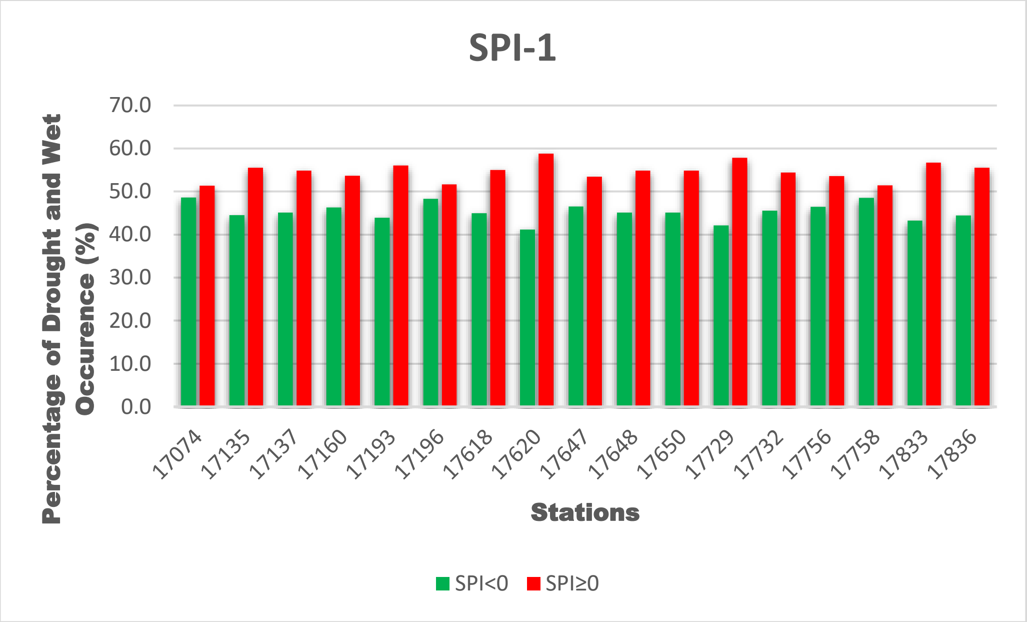
Dry/wet Classification	SPI Class	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24
MD	(-0.99, 0)	30.0	31.1	31.7	27.9	30.2	30.6
MOD	(-1.49, 1)	8.8	8.9	8.5	9.5	9.3	9.7
SD	(-1.99, -1.5)	4.8	4.4	5.1	5.2	5.4	5.0
ED	≤-2	2.6	3.1	3.2	3.4	4.0	4.4
Wet	≥0	53.7	52.4	51.4	53.9	51.0	50.2

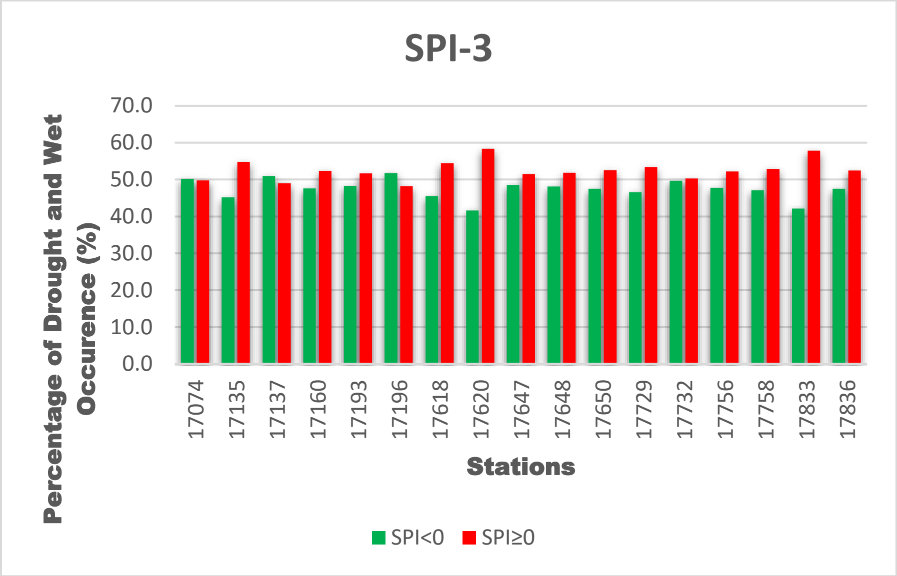
Table 5. 2. Percentages of Minimum and maximum results of SPI categories.

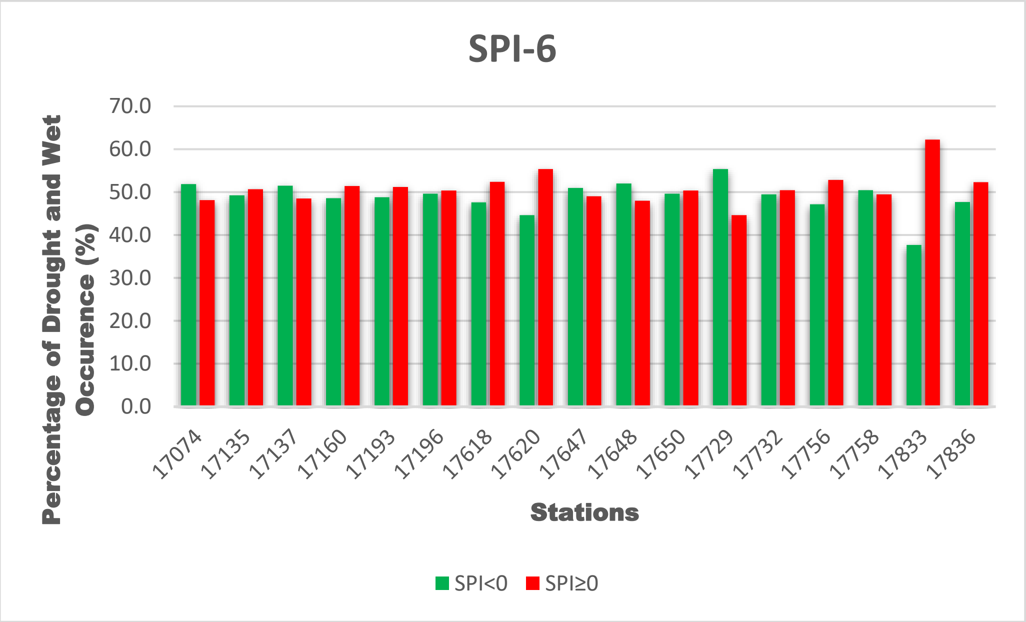
Minimum Percentages							Maximum Percentages						
	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24		SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
MD	25.5	25.7	18.5	18.3	17.6	17.6	MD	33.5	38.1	38.7	38.5	41.4	50.2
MOD	6.8	3.4	6.4	5.6	5.1	1.2	MOD	10.8	12.7	13.2	12.3	14.7	15.2
SD	3.4	2.5	1.5	2.8	1.9	1.9	SD	6.9	6.3	6.3	7.4	8.3	12.7
ED	1.5	2.0	1.7	1.9	1.7	3.2	ED	3.8	4.9	7.4	8.3	8.8	15.2
Wet	51.4	48.2	44.6	46.7	44.5	38.1	Wet	58.8	58.3	62.3	63.0	62.5	60.6
Stations of Minimum Percentages							Stations of Maximum Percentages						
	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24		SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
MD	17729	17833	17833	17833	17137	17137	MD	17196	17196	17729	17648	17648	17648
Wet	17074	17196	17729	17648/ 17074	17648	17648	Wet	17620	17620	17833	17833	17833	17833

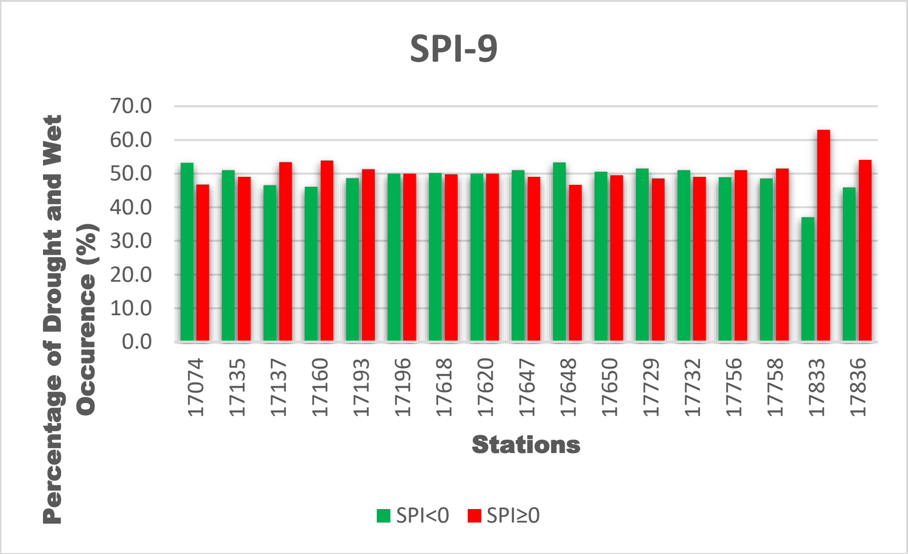
Grouping all of the drought classes as "SPI<0" and all of the wet classes as "SPI≥0" will make the assessment process simpler. Therefore, Figure **5.2** represents station classification of drought (SPI<0) and Wet (SPI≥0) conditions. According to Figure **5.2**, the following results have been concluded:

- Stations17160, 17193 and 17833 have wet percentage higher than those of dry conditions (SPI<0) for all time scale. In addition, stations 17756 and 17836 have values of SPI≥0 superior than those SPI<0 except for 24-month, whereas in station 17650 SPI≥0 is higher than SPI<0 except for 9-month time scale. Station 17732 has got SPI≥0 more than that of SPI<0 except for 9-month and 12-month time scale
- Dry conditions have been observed higher than wet condition in stations 17648 and 17729 except for 1-month and 3-month time scale. Stations 17074 exhibited dry conditions for all time scale except 1-month time scale.
- In general, in SPI-3 3 stations, in SPI-6 6 stations, in SPI-9 8 stations, in SPI-12 9 stations and in SPI-24 10 stations have been observed as dry percentages superior than wet percentages. In contrast, in SPI-1 all stations exhibited wet condition higher than dry condition.


SPI-1
Percentage of Drought and Wet Occurence (%)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
17074
17135
17137
17160
17193
17196
17618
17620
17647
17648
17650
17729
17732
17756
17758
17833
17836
Stations
SPI<0
SPI≥0


SPI-3
Percentage of Drought and Wet Occurence (%)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
17074
17135
17137
17160
17193
17196
17618
17620
17647
17648
17650
17729
17732
17756
17758
17833
17836
Stations
SPI<0
SPI≥0


SPI-6
Percentage of Drought and Wet Occurence (%)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
17074
17135
17137
17160
17193
17196
17618
17620
17647
17648
17650
17729
17732
17756
17758
17833
17836
Stations
SPI<0
SPI≥0


SPI-9
Percentage of Drought and Wet Occurence (%)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
17074
17135
17137
17160
17193
17196
17618
17620
17647
17648
17650
17729
17732
17756
17758
17833
17836
Stations
SPI<0
SPI≥0

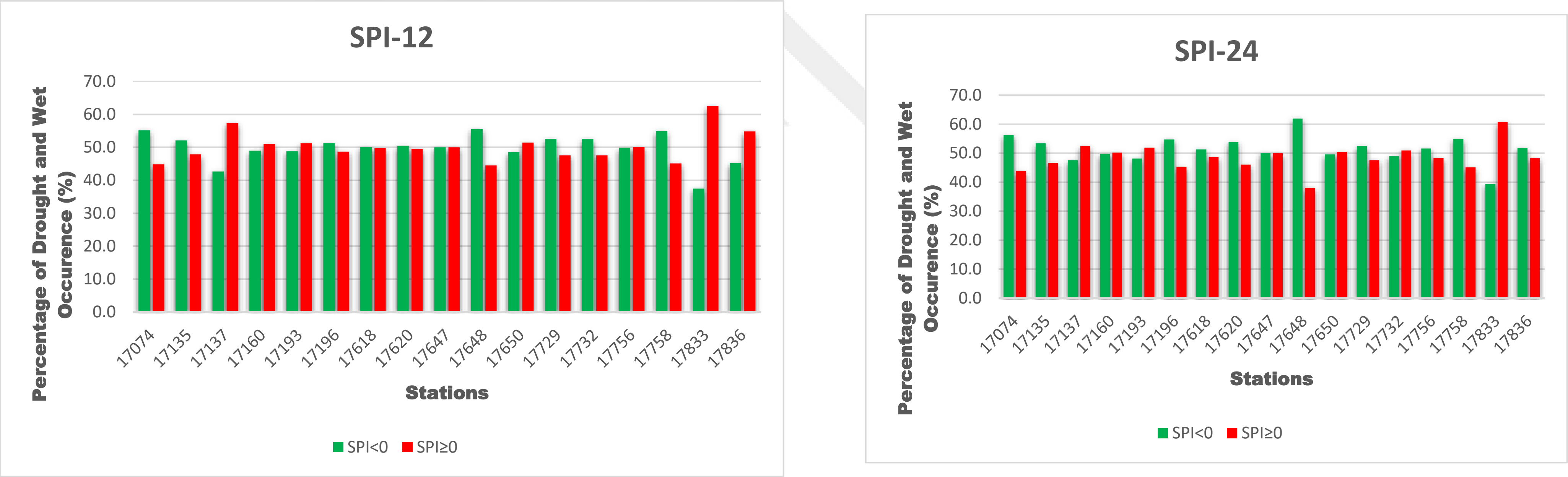


Figure 5. 2. Station classification of drought and Wet conditions.

5.2 Identification of trend analysis by ITA method

ITA is applied to 1, 3, 6, 9, 12 and 24-month SPI series and trend types are identified graphically. In an effort to indicate the trend of each SPI at each station, the symbol +, - and 0 have been employed. SPI series having decreasing trend type are shown by "-", those having increasing trend denoted by "+" and the series that do not have any trend, in which trend slope is equal to 0, are described by "0". For each SPI, the trends both of Severe and Extreme Drought (SED) and Severe and Extreme Wet (SED) have been analyzed. Table **5.3** shows trend types of SPI series of all stations. The graphs for ITA results have been given in Appendix 2. In SPI-1 13, in SPI-3 8, in SPI-6 11, in SPI-9 11, in SPI-12 11 and SPI-24 8 stations have shown a negative trend for Severe and Extreme Drought (SED) category While in SPI-1 9, in SPI-3 11, in SPI-6 10, in SPI-9 11, in SPI-12 11 and SPI-24 12 stations have shown an increasing trend for and Severe and Extreme Wet (SEW) category.

Table 5. 3. Innovative Trend Analysis of selected in Kızılırmak basin. **SEW**: Severe and Extreme Wet, **SED:** Severe and Extreme Drought, **+:** Increasing Trend, **-:** Decreasing Trend, **0:** No Trend

Station	SPI-1		SPI-3		SPI-6		SPI-9		SPI-12		SPI-24	
	SED	SEW	SED	SEW	SED	SEW	SED	SEW	SED	SEW	SED	SEW
17074	0	+	0	+	+	+	+	+	+	+	+	+
17135	-	+	-	+	-	+	-	+	-	+	-	+
17137	-	+	+	+	-	+	-	+	-	+	+	+
17160	0	0	+	+	-	+	+	+	+	+	+	-
17193	-	+	+	-	0	-	+	-	+	0	0	0
17196	-	+	0	+	-	+	-	+	-	+	+	+
17618	-	+	-	+	-	+	-	+	-	0	-	+
17620	-	0	-	-	-	-	-	+	-	+	-	+
17647	-	-	+	+	+	+	+	+	+	+	+	+
17648	+	-	-	-	-	-	-	-	-	-	-	-
17650	-	0	-	+	-	0	-	+	-	+	-	+
17729	0	-	+	-	+	-	+	-	+	-	+	-
17732	-	+	+	+	0	+	-	+	-	+	+	+
17756	-	+	-	+	-	+	-	0	-	0	-	+
17758	-	0	+	-	+	0	+	-	+	-	+	-
17833	-	+	-	+	-	+	-	+	-	+	-	+
17836	-	0	-	0	-	0	-	0	-	+	-	+

Generally, the main result obtained for the SPI-1 values was a negative trend for Severe and Extreme Drought class (SED) and positive trend for Severe and Extreme Wet class (SEW), which is related to heavier droughts and heavier wet periods. In fact, in 8 stations, a positive trend for SEW class and a negative trend for SED class has been detected. These stations are: 17135, 17137, 17193, 17196, 17618, 17732, 17756, and station 17833. In stations 17074 and 17729 have both experienced no trend in SED category but with a different behavior for SEW class. They showed a positive trend and negative trend for SEW category respectively. Differently from previous stations, 4 stations showed no trend for SEW class and a negative trend for SED category. They are: 17620, 17650, 17758 and 17836 station. Moreover, station 17647 and 17648 have experienced a negative trend and positive trend for SED class respectively. However, both of them showed negative trend for SEW class. The results of ITA methods on the station 17160 did not display a clear tendency for the SEW and SED categories.

As regards the 3-months SPI, results are similar to the ones obtained for SPI-1, with a spreading positive trend for the SEW class highest values. As a matter of fact, similar results to SPI-1 have been obtained in 17135, 17618, 17756, and 17833 stations. Stations 17074 and 17836 evidenced positive trends for SEW class and negative trends for SED class respectively. In contrast, they showed no trend for SED class and no trend for SEW class respectively. Stations 17160, 17193, 17647 and 17758 have evidenced results different from the ones obtained for SPI-1. They all experienced a positive trend for SED class but with different trend for SEW class. Stations 17160 and 17647 have experienced both a positive trend for the SEW class (heavier wet periods) whereas a negative trend for SEW class (weaker wet periods) have been detected in stations 17193 and 17758. A negative trend of both SEW and SED categories have been observed in stations 17620 and 17648, thus evidencing heavier droughts and weaker wet periods. In contrast, station 17732 and 17137 have both experienced a positive trend for both SEW and SED categories. At the same time, stations 17650 and 17729 showed different trend. Station 17650 showed heavier wet periods (positive trend in SEW class) and heavier droughts (negative trend in SED class) while station 17729 showed the opposite (weaker wet periods and weaker droughts). Finally, a positive trend for SEW class and no trend for the SED class have been detected in station 17196, thus demonstrating heavier wet periods.

Considering the 6-month SPI, ITA results show same results than SPI-1 and SPI-3 with spreading negative trend for SED class. Generally, results in 7 stations show a negative trend for SED class and a positive trend for SEW class. These stations are: 17135, 17137, 17160, 17196, 17618, 17756 and 17833. By contrast, stations 17193 and 17729 have both evidenced weaker wet periods (a negative trend for SEW class), with concomitant positive trend for SED class (weaker droughts) in station 17729 and with no clear tendency in station 17193. At the same time, a negative trend for SEW and SED categories have been detected in stations 17620 and 17648, whereas station 17074 and 17647 have experienced a positive trend for the two classes. Moreover, no trend has been detected for SEW class in stations 17650, 17758, and 17836 with different results for SED category. While weaker droughts (positive trend for SED class) have been identified in station 17758, all other stations indicated a tendency through heavier droughts (a negative trend for SED class). Finally, in station 17732, a positive trend for SEW class have been detected and they did not show a clear tendency for SED class, thus indicating heavier wet periods.

ITA analysis results of SPI-9 confirm same results than SPI-1, SPI-3 and SPI-6. The main results show a tendency through heavier wet periods and heavier droughts. In fact, a positive trend in SEW class and a negative trend for SED class have been detected in 8 stations namely: 17135, 17137, 17196, 17618, 17620, 17650, 17732, and 17833. By contrast, a positive trend for SED class and a negative trend for SEW class have been evidenced in stations 17193, 17729 and 17758. At the same time, a negative trend for the two categories (SED & SEW) has been noticed in 17648. Whereas, a positive trend the two categories (SED & SEW) have been detected in stations 17074, 17160 and 17647. They are exposed to heavier wet periods and weaker droughts. Finally, stations 17756 and 17836 has experienced a negative trend for SED class has shown no trend for SEW category.

According to long term 12-month SPI analysis, ITA trend analysis main results have given a tendency through heavier droughts and wet periods. In fact, a positive trend for SEW class and a negative trend for SED class have been detected in 8 stations namely: 17135, 17137, 17196, 17620, 17650, 17732, 17833, and 17836. On the contrary, a positive trend for SED class and a negative trend for SEW class have been evidenced in stations 17729 and 17758. At the same time, a negative trend for the two categories (SED & SEW) has been noticed in station 17648. Whereas, a positive trend for SED and SEW classes has been detected in stations 17074, 17160 and 17647. Finally, no trend for SEW class has been detected in 3 stations (17193, 17618 and 17756) but with different trend for SED category. Stations 17618 and 17756 have shown a negative trend while station 17193 have showed a positive trend for SED category.

As regards of SPI-24, ITA trend analysis main results showed same results than SPI-12. Actually, a positive trend for SEW class and a negative trend for SED category have been identified in 7 stations. These stations are 17135, 17618, 17620, 17756, 17650, 17833 and 17836. Different from previous results, a positive trend for SED class and a negative trend for SEW category have been evidenced in stations 17160, 17729 and 17758. At the same time, a negative trend for the two categories (SED & SEW) has been detected in station 17648, thus signifying a heavier droughts and weaker wet periods. Whereas, a positive trend for SED and SEW classes has been noticed in stations 17074, 17137, 17196, 17647 and 17732, thus indicating a clear tendency toward heavier wet periods and weaker droughts. Finally, station 17193 did not show a clear tendency.

As a result, this research has proved that majority of ITA trend analysis applied to SPI time scale values for SED (SPI ≤-1.5) and SEW (SPI ≥1.5) categories is a positive trend and a negative trend respectively. Looking at Table **5.3**, it can be observed that in the majority of the cases a trend is present. Among 204 analyses (6*2*17=204), 88.73% analysis have either an increasing or decreasing trend. The percentage of increasing trend in SEW class is 62.74% and the percentage of decreasing trend in SED class is 60.78%. Some studies proved the results found in this research. Previous study showed that a decreasing trend dominates majority of 7 stations located on Kızılırmak basin (Deger et al. 2023). Another study of trend analysis of monthly average flows of 3 stations located on Kızılırmak basin showed that 2 stations experienced decreasing trend (Minarecioğlu and Çıtakoğlu, 2019).

5.3 Identification of trend by using Mann-Kendall

Mann-Kendall method has been used to investigate trend analysis of each SPI series (1, 3, 6, 9, 12 and 24-month SPI) and to detect trend type by a numerical inspection. Table **5.4** shows trend types of SPI series of all stations based on Mann-Kendall method.

The results in the Table **5.4** showed that majority of the stations experienced a decreasing trend for all SPI series. The percentage of decreasing trend and increasing trend is 67% and 33%, respectively. Some stations showed a monotonic trend for all SPI series, either increasing or decreasing. Stations 17074, 17137, 17193 and 17196 showed an increasing trend for all SPI series. In contrast, Stations 17160, 17620, 17648, 17650, 17732, 17756, 17758, 17833 and 17836 displayed a decreasing trend for all SPI series. In addition, station 17135 showed a decreasing trend only for SPI-1 whereas station 17618 experienced an increasing trend only for SPI-24.

Table 5. 4. Mann-Kendall Analysis of selected stations in Kızılırmak basin

Stations	Z-value						Trend Type					
	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24	1	3	6	9	12	24
17074	2.8297	6.1841	9.1812	10.601	11.341	14.377	+	+	+	+	+	+
17135	-0.19357	0.46034	0.96281	1.1253	1.5495	2.7024	-	+	+	+	+	+
17137	0.60859	0.65399	0.36933	0.3632	1.162	3.6369	+	+	+	+	+	+
17160	-0.43825	-0.11842	-0.48703	-1.2526	-1.7594	-1.8808	-	-	-	-	-	-
17193	0.99601	0.8454	0.81927	0.84555	0.80357	1.9878	+	+	+	+	+	+
17196	2.7045	4.6285	6.9819	8.3525	9.5185	12.517	+	+	+	+	+	+
17618	-1.3604	-1.223	-1.1687	-1.0538	-1.0833	0.18603	-	-	-	-	-	+
17620	-0.37301	-0.52271	-1.3632	-1.6258	-1.8049	-1.5239	-	-	-	-	-	-
17647	0.55092	0.15215	-0.35705	-0.37914	-0.18651	1.3202	+	+	-	-	-	+
17648	-2.9255	-4.3124	-5.3195	-5.5403	-5.7701	-5.964	-	-	-	-	-	-
17650	-0.66735	-0.95836	-1.5105	-1.9226	-2.0655	-1.2802	-	-	-	-	-	-
17729	0.35706	-0.38528	-0.99019	-1.1264	-1.281	-0.26871	+	-	-	-	-	-
17732	-0.80489	-0.42215	-0.74787	-0.85121	-0.55231	-0.25111	-	-	-	-	-	-
17756	-1.1726	-1.1047	-1.1489	-1.2899	-1.4275	-1.59	-	-	-	-	-	-
17758	-0.79635	-1.5411	-1.9988	-1.8687	-1.4957	-0.16196	-	-	-	-	-	-
17833	-4.6804	-6.4616	-7.3434	-7.3197	-7.6116	-8.3532	-	-	-	-	-	-
17836	-0.68982	-0.84093	-0.98729	-1.2694	-1.6648	-3.4114	-	-	-	-	-	-

CHAPITER VI

CONCLUSION

In general, trend detection techniques enable researchers to examine general tendencies in climate variables. In this study, an average SPI series has been analyzed at various time periods (1, 3, 6, 9, 12 and 24 months) for 17 stations in the Kızılırmak basin. The SPI values obtained were used to perform a meteorological drought analysis. The number of months with severe and extreme dry or wet conditions have been detected for each SPI. Severe and Extreme Dry (SED) categories are considered as SPI≤-1.5 and Severe and Extreme Wet (SEW) categories as SPI≥1.5. Finally, the SPI series was then subjected to a graphical approach based on the Innovative Trend Analysis (ITA) suggested by Şen and numerical approach based on Mann-Kendall method. According to SPI results, for all time scale, the number of months showing dry conditions is higher than the ones showing wet conditions. In stations 17074, 17160, 17193, 17618, and 17833; the number of months with severe and extreme dry conditions outperform those of wet conditions for all time scale. After examining the four drought categories—Moderate Drought (MOD), Severe Drought (SD), Extreme Drought (ED), and Mild Drought (MD), where all SPI positive values ($SPI \geq 0$) are classified as "wet"—it has been determined that the wet class and MD class have the highest percentage of occurrences. Upon analyzing drought classes, it is observed that, except at the 24-month time scale, Moderate Drought consistently exhibits the highest minimum and maximum percentages among the Moderate, Severe, and Extreme drought classes. Additionally, Severe Drought has a higher minimum percentage than Extreme Drought, except at the 6-month and 24-month time scales, whereas Extreme Drought has a higher maximum percentage than Severe Drought, except at the 1-month and 3-month time scales. Combining all drought classes as "SPI<0" and categorizing positive SPI values as "wet," it is observed that in SPI-3 3 stations, SPI-6 6 stations, in SPI-9 8 stations, in SPI-12 9 stations, and in SPI-24 10 stations had dry percentages higher than wet percentages. However, in SPI-1, all stations exhibited wet percentages higher than dry percentages. ITA technique is developed by adding two vertical lines to detect possible trends. These trends are composed of three cases: an increasing trend, a decreasing trend and no trend. For each SPI, the trends both of Severe and Extreme Drought (SED) and Severe and Extreme Wet (SED) is examined. For ITA graphical analysis, the majority of results for all time scale showed a trend (89%). While a negative trend of SPI value under the dry categories indicates the presence of heavier drought, a positive trend shows no drought. In contrast, an increasing trend of SPI value under wet category demonstrates the presence of wet significantly, whereas a decreasing trend means weaker wet periods. The main result obtained was a negative trend for Severe and Extreme Drought class (SED) and positive trend for Severe and Extreme Wet class (SEW), which is related to heavier droughts and heavier wet periods. It is also worth to state that some of stations have demonstrated decreasing trend in the majority of time scale whereas other stations have shown increasing trend in the majority of time scale. Among all stations; stations 17618 (6 cases), 17620 (8 cases), 17648 (11 cases), 17650 (6 cases), 17729 (6 cases), 17756 (6 cases) and 17836 (6 cases) have shown a negative trend in time scales (1, 3, 6, 9, 12 and 24) of SPI values. In contrast; stations 17074 (12 cases), 17137 (8 cases), 17160 (8 cases), 17196 (7 cases), 17647 (10 cases), and 17732 (8 cases) have shown an increasing trend in all time scales of SPI values for both SED and SEW categories. Station 17074 (12 cases) and station 17648 (11 cases) have the highest number of positive trend case and negative trend case which is 12 and 11 cases, respectively. Based on ITA analysis of SEW and SED categories, it has been observed for four stations the positive trend and negative trend are equal. These stations are: 17135, 17193, 17758 and 17833. According to Mann-Kendall analysis results, decreasing and increasing trends account for 67% and 33%, respectively. It is worth to notice that, according to Mann-Kendall test, some stations displayed a monotonic trend that was either increasing or declining for all time scale. Overall results demonstrate that there is an increase in wet categories in some parts of the basin parts and a large increase in dry conditions in other parts of the basin. In order to protect water supplies from potential future droughts, analyses have suggested that the basin needs an effective drought management plan. Therefore, it is anticipated that the results findings will be helpful for basin and water resources management drought action plans.

REFERENCES

Achite M, Simsek O, Adarsh S, et al (2023) Assessment and monitoring of meteorological and hydrological drought in semiarid regions: The Wadi Ouahrane basin case study (Algeria). Physics and Chemistry of the Earth, Parts A/B/C 130:103386. https://doi.org/10.1016/j.pce.2023.103386

Ahmadi B, Moradkhani H (2019) Revisiting hydrological drought propagation and recovery considering water quantity and quality. Hydrological Processes 33:1492–1505. https://doi.org/10.1002/hyp.13417.

Akturk G, Zeybekoglu U, Yildiz O (2022) Assessment of meteorological drought analysis in the Kizilirmak River Basin, Turkey. Arab J Geosci 15:850. https://doi.org/10.1007/s12517-022-10119-0

Alam J, Saha P, Mitra R, Das J (2023) Investigation of spatio-temporal variability of meteorological drought in the Luni River Basin, Rajasthan, India. Arab J Geosci 16:201. https://doi.org/10.1007/s12517-023-11290-8

Annual 2023 Global Climate Report | National Centers for Environmental Information (NCEI). (n.d.). https://www.ncei.noaa.gov/access/monitoring/monthly-report/global/202313#:~:text=The%20year%202023%20was%20the,decade%20(2014%E2%80%932023).

Ashok K. Mishra, Vijay P. Singh, (2010). A review of drought concepts. Journal of Hydrology 391 (2010) 202–216.

Ashraf MS, Shahid M, Waseem M, et al (2023) Assessment of Variability in Hydrological Droughts Using the Improved Innovative Trend Analysis Method. Sustainability 15:9065. https://doi.org/10.3390/su15119065

Bacanlı, Ü. G., Dikbaş, F., Baran, T. (2012). Kuraklık Analizinde Entropi Yöntemi. VII. Ulusal Hidroloji Kongresi.26-27 Eylül2012, Süleyman Demirel Üniversitesi, Isparta.

Berhail S, Tourki M, Merrouche I, Bendekiche H (2022) Geo-statistical assessment of meteorological drought in the context of climate change: case of the Macta basin (Northwest of Algeria). Model Earth Syst Environ 8:81–101. https://doi.org/10.1007/s40808-020-01055-7

Bhunia P, Das P, Maiti R (2020) Meteorological Drought Study Through SPI in Three Drought Prone Districts of West Bengal, India. Earth Syst Environ 4:43–55. https://doi.org/10.1007/s41748-019-00137-6

Buffoni, L., Maugeri, M., & Nanni, T. (1999). Precipitation in Italy from 1833 to 1996. Theoretical and Applied Climatology, 63(1), 33-40.

Burn, D. H. & Elnur, M.A.H. (2002). Detection of hydrologic trends and variability. Journal of Hydrology, 255(1-4), 107-122.

Çakmak, B. (2002). Kızılırmak Havzası Sulama Birliklerinde Sulama System Performansının Değerlendirilmesi. KSU Fen ve Mühendislik Dergisi, 5(2), 130-141.

Caloiero (2018) Drought Analysis in Europe and in the Mediterranean Basin Using the Standardized Precipitation Index. https://doi.org/10.3390/w10081043

Castano, A. (2013). Monitoring Drought at river basin and regional scale: application in Sicily, p.6.

Chaisson,S. (2012). Water Scarcity Issues and Implications, Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Master of Arts in The Department of Geography and Anthropology by Samantha Chaisson BA, Louisiana State University, p.35.

Chopra, P. (2006). Drought risk assessment using remote sensing and GIS: a case study of Gujarat. International Journal of Disaster Risk Science, 4(3).

Chopra.P. (2006). Drought risk assessment using remote sensing and GIS: a case study of Gujarat, ME thesis, Indian Institute of Remote Sensing, Dehradun & International Institute for Geo-information & Earth Observation, the Netherlands.

Climate change in the Mediterranean | UNEPMAP. (n.d.). https://www.unep.org/unepmap/resources/factsheets/climate-change.

Corti, T., Muccione, V., Köllner-Heck, P., Bresch, D., & Seneviratne, S. I. (2009). Simulating past droughts and associated building damages in France. Hydrology and Earth System Sciences, 13(9). https://doi.org/10.5194/hess-13-1739-2009

Dabanlı İ, Mishra AK, Şen Z (2017) Long-term spatio-temporal drought variability in Turkey. Journal of Hydrology 552:779–792. https://doi.org/10.1016/j.jhydrol.2017.07.038

Dai, A. (2011). Drought under global warming: A review. Wiley Interdisciplinary Reviews: Climate Change, 2(1), 45–65. http://doi.org/10.1002/wcc.81

Dai, A. (2013). Increasing drought under global warming in observations and models. Nature Climate Change, 3(1). https://doi.org/10.1038/nclimate1633

Das J, Bhattacharya SK (2018) Trend analysis of long-term climatic parameters in Dinhata of Koch Bihar district, West Bengal. Spat Inf Res 26:1–10. https://doi.org/10.1007/s41324-018-0173-3

Das J, Gayen A, Saha P, Bhattacharya SK (2020d) Meteorological drought analysis using standardized precipitation index over Luni Basin in Rajasthan, India. SN Appl Sci 2. https://doi.org/10.1007/s42452-020-03321-w

Deger İH, Yüce Mİ, Eşit M (2023) An Investigation of Hydrological Drought Characteristics in Kızılırmak Basin, Türkiye: Impacts and Trends. Bitlis Eren Üniversitesi Fen Bilimleri Dergisi 12:126–139. https://doi.org/10.17798/bitlisfen.1200742

DEGER, I. H., YUCE, M. I.& ESIT, M. (2023). An Investigation of Hydrological Drought Characteristics in Kızılırmak Basin, Türkiye: Impacts and Trends. Bitlis Eren University Journal of Science, 12, 126-139.

Déry, S. J., & Wood, E. F. (2005). Decreasing river discharge in northern Canada. Geophysical Research Letters, 32(10).

Diffenbaugh, N. S., & Giorgi, F. (2012). Climate change hotspots in the CMIP5 global climate model ensemble. Climatic change, 114(3-4), 813-822. http://doi.org/10.1007/s10584-012-0570-x

Drought and Climate Change. (2021, January 28). Center for Climate and Energy Solutions. https://www.c2es.org/content/drought-and-climate-change/

Drought Basics. (n.d.). Drought.gov. https://www.drought.gov/what-is-drought/drought-basics

Drought. (2023, November 2). Drought. https://www.who.int/health-topics/drought#tab=tab_1

Dufera JA, Yate TA, Kenea TT (2023) Spatiotemporal analysis of drought in Oromia regional state of Ethiopia over the period 1989 to 2019. Nat Hazards 117:1569–1609. https://doi.org/10.1007/s11069-023-05916-z

Edwards DC (1997) Characteristics of 20th Century drought in the United States at multiple time scales. Air Force Inst of Tech Wright-Patterson Afb Oh.

Elouissi A, Benzater B, Dabanli I, et al (2021) Drought investigation and trend assessment in Macta watershed (Algeria) by SPI and ITA methodology. Arab J Geosci 14:1329. https://doi.org/10.1007/s12517-021-07670-7

Emmanuel, P., Agbo., U., Nkajoe., C., O., Edet. (2022). Comparison of Mann–Kendall and Şen's innovative trend method for climatic parameters over Nigeria's climatic zones. Climate Dynamics, doi: 10.1007/s00382-022-06521-9

Ercan, Burcu. (2016). DETERMINATION OF THE RAINFALL-RUNOFF RELATIONSHIP FOR KIZILIRMAK BASIN.

Esit M (2022) Investigation of innovative trend approaches (ITA with significance test and IPTA) comparing to the classical trend method of monthly and annual hydrometeorological variables: a case study of Ankara region, Turkey. Journal of Water and Climate Change 14:305–329. https://doi.org/10.2166/wcc.2022.356

Eşit M, Yüce Mİ (2022) Çok Değişkenli Kuraklık Frekans Analizi ve Risk Değerlendirmesi: Kahramanmaraş Örneği. Doğal Afetler ve Çevre Dergisi 8:368–382. https://doi.org/10.21324/dacd.1066958

Esit M, Yuce MI (2023) Copula-based bivariate drought severity and duration frequency analysis considering spatial–temporal variability in the Ceyhan Basin, Turkey. Theor Appl Climatol 151:1113–1131. https://doi.org/10.1007/s00704-022-04317-9

Fatma, Akcay., Bilal, Bingölbali., Adem, Akpınar., Murat, Kankal. (2022). Trend detection by innovative polygon trend analysis for winds and waves. Frontiers in Marine Science, doi: 10.3389/fmars.2022.930911

Gampe, D., Ludwig, R., Qahman, K., & Afifi, S. (2016). Applying the Triangle Method for the parameterization of irrigated areas as input for spatially distributed hydrological modeling - Assessing future drought risk in the Gaza Strip (Palestine). Science of the Total Environment, 543, 877–888. http://doi.org/10.1016/j.scitotenv.2015.07.098

Gilbert, R.O., 1987. Statistical methods for environmental pollution monitoring. Van Nostrand Reinhold, New York.

G. Tsakiris vd., “Drought characterization. Drought management guidelines technical annex, 58, 85-102.”, 2007.

Gumus V, Algin HM (2017) Meteorological and hydrological drought analysis of the Seyhan−Ceyhan River Basins, Turkey. Meteorological Applications 24:62–73. https://doi.org/10.1002/met.1605

Gumus V, Simsek O, Avsaroglu Y, Agun B (2021) Spatio-temporal trend analysis of drought in the GAP Region, Turkey. Nat Hazards 109:1759–1776. https://doi.org/10.1007/s11069-021-04897-1

Hayes M, Svoboda M, Wall N, Widhalm M (2011) The Lincoln Declaration on Drought Indices: Universal Meteorological Drought Index Recommended.

Bulletin of the American Meteorological Society 92:485–488. https://doi.org/10.1175/2010BAMS3103.1

Johnson, L. E. (2009). Geographic Information Systems in Water Resources Engineering. CRC Press, America.

Kao, S. C., & Govindaraju, R. S. (2010). A copula-based joint deficit index for droughts. Journal of Hydrology, 380(1–2). https://doi.org/10.1016/j.jhydrol.2009.10.029

Karl , T.R.,Young, P.J . (1987). The 1 986 southeast drought in historical perspective. Bulletin ofthe American Meteorological Society, 68(7), pp.773-778.

Katipoğlu OM, Acar R, Şenocak S (2021) Spatio-temporal analysis of meteorological and hydrological droughts in the Euphrates Basin, Turkey. Water Supply 21:1657–1673. https://doi.org/10.2166/ws.2021.019

Kendall MG (1975) Rank correlation measures, vol 202. Charles Griffin, London, p 15

Kendall, M.G. (1975). Rank Correlation Methods; Charles Griffin: London, 1975.

Kheyruri Y, Nikaein E, Sharafati A (2023) Spatial monitoring of meteorological drought characteristics based on the NASA POWER precipitation product over various regions of Iran. Environ Sci Pollut Res 30:43619–43640. https://doi.org/10.1007/s11356-023-25283-3

Khorrami B, Gorjifard S, Ali S, Feizizadeh B (2023a) Local-scale monitoring of evapotranspiration based on downscaled GRACE observations and remotely sensed data: An application of terrestrial water balance approach. Earth Sci Inform 16:1329–1345. https://doi.org/10.1007/s12145-023-00964-2

Khorrami B, Pirasteh S, Ali S, et al (2023b) Statistical downscaling of GRACE TWSA estimates to a 1-km spatial resolution for a local-scale surveillance of flooding potential. Journal of Hydrology 624:129929. https://doi.org/10.1016/j.jhydrol.2023.129929

Kumar, V., Jain, S. K., & Singh, Y. (2010). Analysis of long-term rainfall trends in India. Hydrological Sciences Journal–Journal des Sciences Hydrologiques, 55(4), 484-496.

Lu, E.,Luo, Y.,Zhang, R.,Wu, Q.,Liu, L. (2011). Regional atmospheric anomalies responsible for the 2009–2010 severe drought in China, Journal of Geophysical Research,Atmospheres (1984–2012), vol.116,Issue D21.

Mallick J, Talukdar S, Alsubih M, et al (2021) Analysing the trend of rainfall in Asir region of Saudi Arabia using the family of Mann-Kendall tests, innovative trend analysis, and detrended fluctuation analysis. Theor Appl Climatol 143:823–841. https://doi.org/10.1007/s00704-020-03448-1

Mann H B 1945 Econometrica: Journal of the Econometric Society 245-259.

Mann HB (1945) Nonparametric tests against trend. Econometrica 13(3): 245–259. doi:10.2307/1907187

McKee TB, Doesken NJ, Kleist J (1993) The relationship of drought frequency and duration to time scales. In: Proceedings of the 8th Conference on Applied Climatology. California, pp 179–183

McKee TB (1995) Drought monitoring with multiple time scales. In: Proceedings of 9th Conference on Applied Climatology, Boston, 1995

Michael, G., Cottam. (2022). The Procedure of Detecting Drought Trend by Using Şen's Innovative Trend Analysis Methodology. doi: 10.22541/au.167117423.37811884/v1

MİNARECİOĞLU N, ÇITAKOĞLU H (2019) Trend Analysis of Monthly Average Flows of Kizilirmak Basin. Journal of Anatolian Environmental and Animal Sciences 4:454–459

Mishra, A. K., & Singh, V. P. (2010). A review of drought concepts. Journal of Hydrology, 391(1-2), 202–216. http://doi.org/10.1016/j.jhydrol.2010.07.012.

Mishra, A. K., & Singh, V. P. (2011). Drought modeling - A review. In Journal of Hydrology (Vol. 403, Issues 1–2). https://doi.org/10.1016/j.jhydrol.2011.03.049

Mondal, A., Kundu, S., & Mukhopadhyay, A. (2012). Rainfall trend analysis by Mann-Kendall test: A case study of north-eastern part of Cuttack district, Orissa. International Journal of Geology, Earth and Environmental Sciences, 2(1), 70-78.

Mondal, Arun & Kundu, Sananda & Mukhopadhyay, Anirban. (2012). Rainfall trend analysis by Mann-Kendall test: a case study of North-Eastern part of Cuttack district, Orissa. Int. J. Geol. Earth Environ. Sci.. 2

Moradi, HR.,Rajabi, M.,Faragzadeh, M. (2011). Investigation of meteorological drought characteristics in Fars province, Iran, Catena,vol.84, pp.35-46.

.Muse NM, Tayfur G, Safari MJS (2023) Meteorological Drought Assessment and Trend Analysis in Puntland Region of Somalia. Sustainability 15:10652. https://doi.org/10.3390/su151310652

Nafarzadegan, A. R., Rezaeian Zadeh, M., Kherad, M., Ahani, H., Gharehkhani, A., Karampoor, M. A., & Kousari, M. R. (2012). Drought area monitoring during the past three decades in Fars province, Iran. Quaternary International, 250. https://doi.org/10.1016/j.quaint.2010.12.009

Nafarzadegan, AR.,Zadeh, M Rezaeian.,Kherad, M.,Ahani, H.,Gharehkhani, A.,Karampoor, MA.,Kousari, MR. (2012) . Drought area monitoring during the past three decades in Fars province, Iran, Quaternary International, vol.250, pp.27-36.

Nagarajan.R. (2010). Drought assessment, Springer Science & Business Media,ISBN 9048125006, pp.2-8.

Niaz R, Almazah MMA, Al-Rezami AY, et al (2023) Proposing a new framework for analyzing the severity of meteorological drought. Geocarto International 38:2197512. https://doi.org/10.1080/10106049.2023.2197512

Niemeyer S (2008) New drought indices. Options Méditerranéennes Série A: Séminaires Méditerranéens 80:267–274

Oğuztürk, G. (2010). Kızılırmak Havzası'nda SYİ ile kuraklık analizi ve YSA yöntemi ile kuraklık tahmini / A drought analysis of the Kızılırmak basin using the standardized precipitation index (SPI) method and drought estimation using the artificial neural networks method, Yüksek lisans tezi, Kırıkkale Üniversitesi.

Olukayode Oladipo, E. (1985). A comparative performance analysis of three meteorological drought indices. Journal of Climatology, 5(6). https://doi.org/10.1002/joc.3370050607

Pearson ES, Hartley HO (1966) Biometrika tables for statisticians, vol 1, 3rd edn. Cambridge University Press, London

Rahman A. T. M. S, Jahan CS,Mazumder QH, Kamruzzaman Md, Hosono T, (2017) Drought analysis and its implication in sustainable water resource management in Barind area, Bangladesh. Journal of the Geological Society of India 89 (1):47–56

Rahman A. T. M. S, Kamruzzaman MD, Jahan CS, Mazumder QH, Hossain A (2016) Evaluation of spatio-temporal dynamics of water table in NW Bangladesh: an integrated approach of GIS and Statistics. SustainableWater Resources Management 2 (3):297–312

Rahman, M. R., & Lateh, H. (2017). Climate change in Bangladesh: a spatio-temporal analysis and simulation of recent temperature and rainfall data using GIS and time series analysis model. Theoretical and Applied Climatology, 128(1–2). https://doi.org/10.1007/s00704-015-1688-3

RICHAR DR. HEIM JR, (2002). A Review of Twentieth Century Drought Indices Used in the United States. Richard R. Heim Jr., Climate Monitoring Branch, Scientific Services Division, National Climatic Data Center, 151 Patton Avenue, Asheville, NC 28801-5001.

Sadık, Alashan. (2023). Non-monotonic trend analysis using Mann-Kendall with self-quantiles. doi: 10.22541/essoar.167751622.23605443/v1.

Santos, Nuno & Hess, Sebastian & Jamali Jaghdani, Tinoush. (2016). Water along the Food Chain: Turkey.

Selcuk Ozturk D, Uke Keskin A, Zeybekoglu U. 2023. Meteorological and hydrological drought analysis of the Kızılırmak basin. BSJ Agri, 6(4): 427-438.

Sen PK (1968). Estimates of the regression coefficient based on Kendall’s tau. Journal of American Statistical Association 39, 1379–1389.

Şen, Z. An innovative trend analysis methodology. J. Hydrol. Eng. 2012, 17, 1042–1046. [CrossRef].

Şen Z (2012) Innovative Trend Analysis Methodology. Journal of Hydrologic Engineering 17:1042–1046. https://doi.org/10.1061/(ASCE)HE.1943-5584.0000556

Şen Z (2017) Innovative trend significance test and applications. Theor Appl Climatol 127:939–947. https://doi.org/10.1007/s00704-015-1681-x

Şen, Z. Trend identification simulation and application. J. Hydrol. Eng. 2014, 19, 635–642. [CrossRef]

Serrano A. Mateos VL. Garcia JA. (1999). Trend analysis of monthly precipitation over the Iberian Peninsula for the Period 1921–1995. Physics and Chemistry of the Earth 24(1–2), 85–90.

Shiau JT, Modarres R (2009) Copula-based drought severity-duration-frequency analysis in Iran. Meteorological Applications 16:481–489. https://doi.org/10.1002/met.145

Shiau, J. T., & Modarres, R. (2009). Copula-based drought severity-duration-frequency analysis in Iran. Meteorological Applications, 16(4). https://doi.org/10.1002/met.145

Simsek O (2021) Hydrological drought analysis of Mediterranean basins, Turkey. Arab J Geosci 14:2136. https://doi.org/10.1007/s12517-021-08501-5

Simsek O, Yildiz-Bozkurt S, Gumus V (2023) Analysis of meteorological drought with different methods in the Black Sea region, Turkey. Acta Geophys. https://doi.org/10.1007/s11600-023-01099-0

Smith, A. B. (2022). 2020 U.S. billion-dollar weather and climate disasters in historical context. NOAA Climate.

Soylu Pekpostalci D, Tur R, Danandeh Mehr A (2023) Spatiotemporal Variations in Meteorological Drought Across the Mediterranean Region of Turkey. Pure Appl Geophys. https://doi.org/10.1007/s00024-023-03312-z

Suhana L, Tan ML, Luhaim Z, et al (2023) Spatiotemporal characteristics of hydro-meteorological droughts and their connections to large-scale atmospheric circulations in the Kelantan River Basin, Malaysia. Water Supply 23:2283–2298. https://doi.org/10.2166/ws.2023.126

Sun, C.,Ma, Y. (2015). Effects of non-linear temperature and precipitation trends on Loess Plateau droughts, Quaternary International, ISSN 1040-6182.

Sun P, Liu R, Yao R, et al (2023) Responses of agricultural drought to meteorological drought under different climatic zones and vegetation types. Journal of Hydrology 619:129305. https://doi.org/10.1016/j.jhydrol.2023.129305

Tarım ve Orman Bakanlığı, “Kızılırmak Havzası Taşkın Yonetim Plani Yönetici Özeti”. T.C. Tarım ve Orman Bakanlığı, 2019. [Online].

Thiele, O.,Schiffer, R.A. ( ). Understanding climate - A strategy for climate.Modeling and Predictability Research, NASA Reference Publication, 1 1 58, pp. 31.

Thi NQ, Govind A, Le M-H, et al (2023) Spatiotemporal characterization of droughts and vegetation response in Northwest Africa from 1981 to 2020. The Egyptian Journal of Remote Sensing and Space Science 26:393–401. https://doi.org/10.1016/j.ejrs.2023.05.006

Thom HCS (1966) Some methods of climatological analysis, World Meteorological Organization (WMO), Technical Note No. 81 (WMO - No. 199.TP.I03), Geneva, Switzerland, 69ss.

Topçu E, Seçkin N, Haktanır NA (2022) Drought analyses of Eastern Mediterranean, Seyhan, Ceyhan, and Asi Basins by using aggregate drought index (ADI). Theor Appl Climatol 147:909–924. https://doi.org/10.1007/s00704-021-03873-w

Trenberth, K. E. (2011). Changes in precipitation with climate change. Climate Research, 47(1-2), 123-138. https://doi.org/10.3354/cr00953

Trenberth, K E.,Guillemot, C J. (1996) . Physical processes involved in the 1988 drought and 1993 floods in North America, Journal of Climate, vol.6, pp.1288-1298.

Türkeş, M. ve Yıldız, D. 2014. Türkiye'de Hidroelektrik Santrallerin Geleceği

Ullah, I., Ma, X., Yin, J., Omer, A., Habtemicheal, B. A., Saleem, F., Iyakaremye, V., Syed, S., Arshad, M., & Liu, M. (2023). Spatiotemporal characteristics of meteorological drought variability and trends (1981–2020) over South Asia and the associated large-scale circulation patterns. Climate Dynamics, 60(7–8). https://doi.org/10.1007/s00382-022-06443-6

Ullah I, Ma X, Yin J, et al (2023) Spatiotemporal characteristics of meteorological drought variability and trends (1981–2020) over South Asia and the associated large-scale circulation patterns. Clim Dyn 60:2261–2284. https://doi.org/10.1007/s00382-022-06443-6

URL < http:// www.drought.unl.edu/> , data retrived 15.04.2015.

Van der Molen, M. K., Dolman, A. J., Ciais, P., Eglin, T., Gobron, N., Law, B. E., Meir, P., Peters, W., Phillips, O. L., Reichstein, M., Chen, T., Dekker, S. C., Doubková, M., Friedl, M. A., Jung, M., van den Hurk, B. J. J. M., de Jeu, R. A. M., Kruijt, B., Ohta, T., … Wang, G. (2011). Drought and ecosystem carbon cycling. Agricultural and Forest Meteorology, 151(7), 765–773. https://doi.org/10.1016/J.AGRFORMET.2011.01.018

Venkataraman, K., Tummuri, S., Medina, A., & Perry, J. (2016). 21st century drought outlook for major climate divisions of Texas based on CMIP5 multimodel ensemble: Implications for water resource management. Journal of Hydrology, 534, 300–316. http://doi.org/10.1016/j.jhydrol.2016.01.001

Vörösmarty CJ. Green P. Salisbury J. Lammers RB (2000). Global water resources: vulnerability from climate changes and population growth. Science 289, 284–288. (EDO), E. D. (2020). Standardized Precipitation Index (SPI). Copernicus

World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2016: Handbook of Drought Indicators and Indices (M. Svoboda and B.A. Fuchs). Integrated Drought Management Programme (IDMP), Integrated Drought Management Tools and Guidelines Series 2. Geneva.

WMO. 1997. Extreme agrometeorological events. CagM-X Working Group, Geneva, Switzerland, pp: 193.

Yang P, Zhai X, Huang H, et al (2023) Association and driving factors of meteorological drought and agricultural drought in Ningxia, Northwest China. Atmospheric Research 289:106753. https://doi.org/10.1016/j.atmosres.2023.106753

Yanmaz, A. M. (2013). Applied Water Resources Engineering. 4th Edition. Çankaya-Ankara: Tarcan Matbaacılık Yay. San.

Yuce MI, Deger IH, Esit M (2023) Hydrological drought analysis of Yeşilırmak Basin of Turkey by streamflow drought index (SDI) and innovative trend analysis (ITA). Theor Appl Climatol. https://doi.org/10.1007/s00704-023-04545-7

Yuce MI, Esit M (2021) Drought monitoring in Ceyhan Basin, Turkey. Journal of Applied Water Engineering and Research 9:293–314. https://doi.org/10.1080/23249676.2021.1932616

Zhou, H., Zhou, W., Liu, Y., Huang, J., Yuan, Y., & Liu, Y. (2023). Climatological spatial scales of meteorological droughts in China and associated climate variability. Journal of Hydrology, 617. https://doi.org/10.1016/j.jhydrol.2022.129056.

APPENDIX

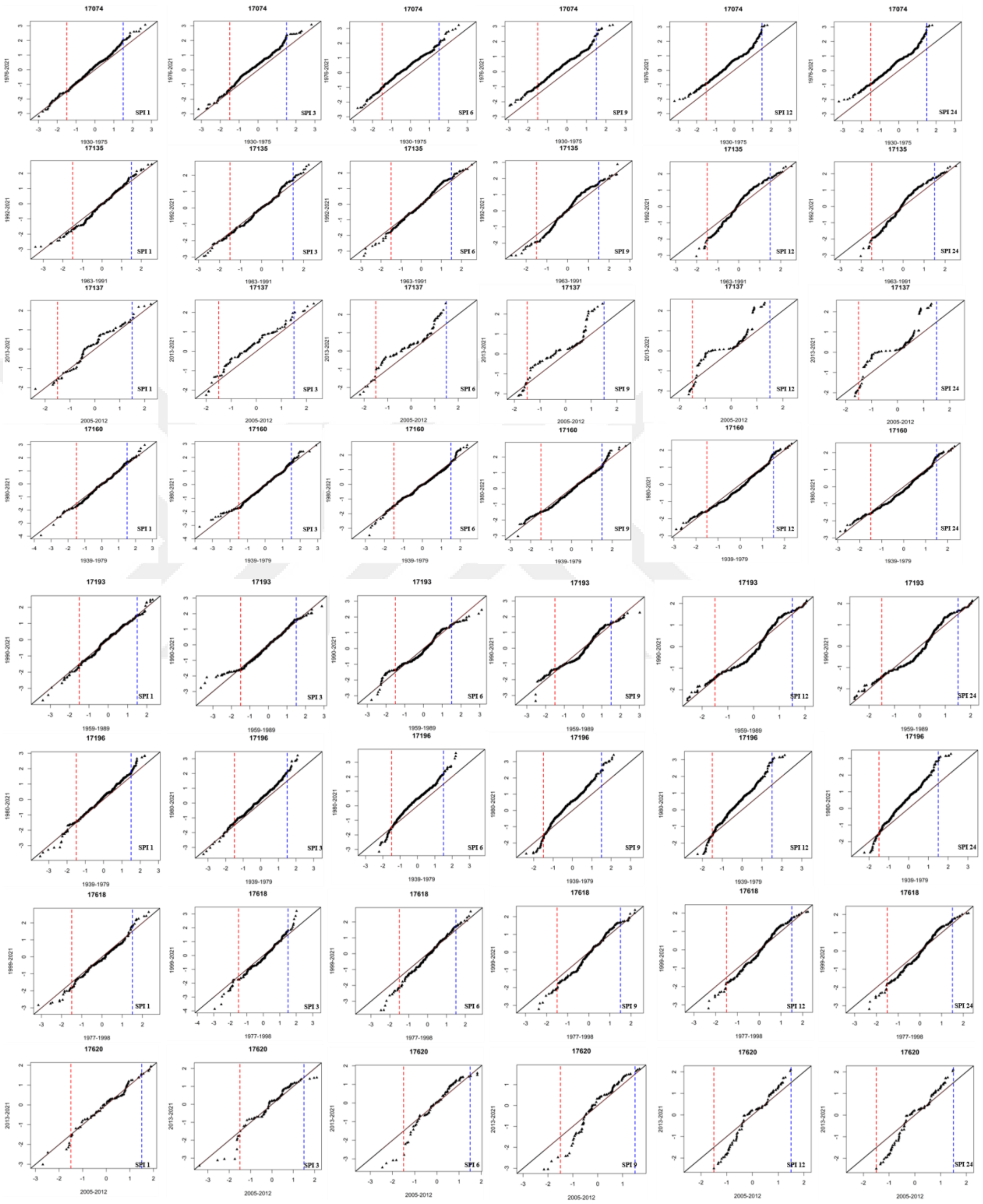
Appendix A.

Table A.1 The number of severe and extreme dry and severe and extreme wet months in 17 stations.

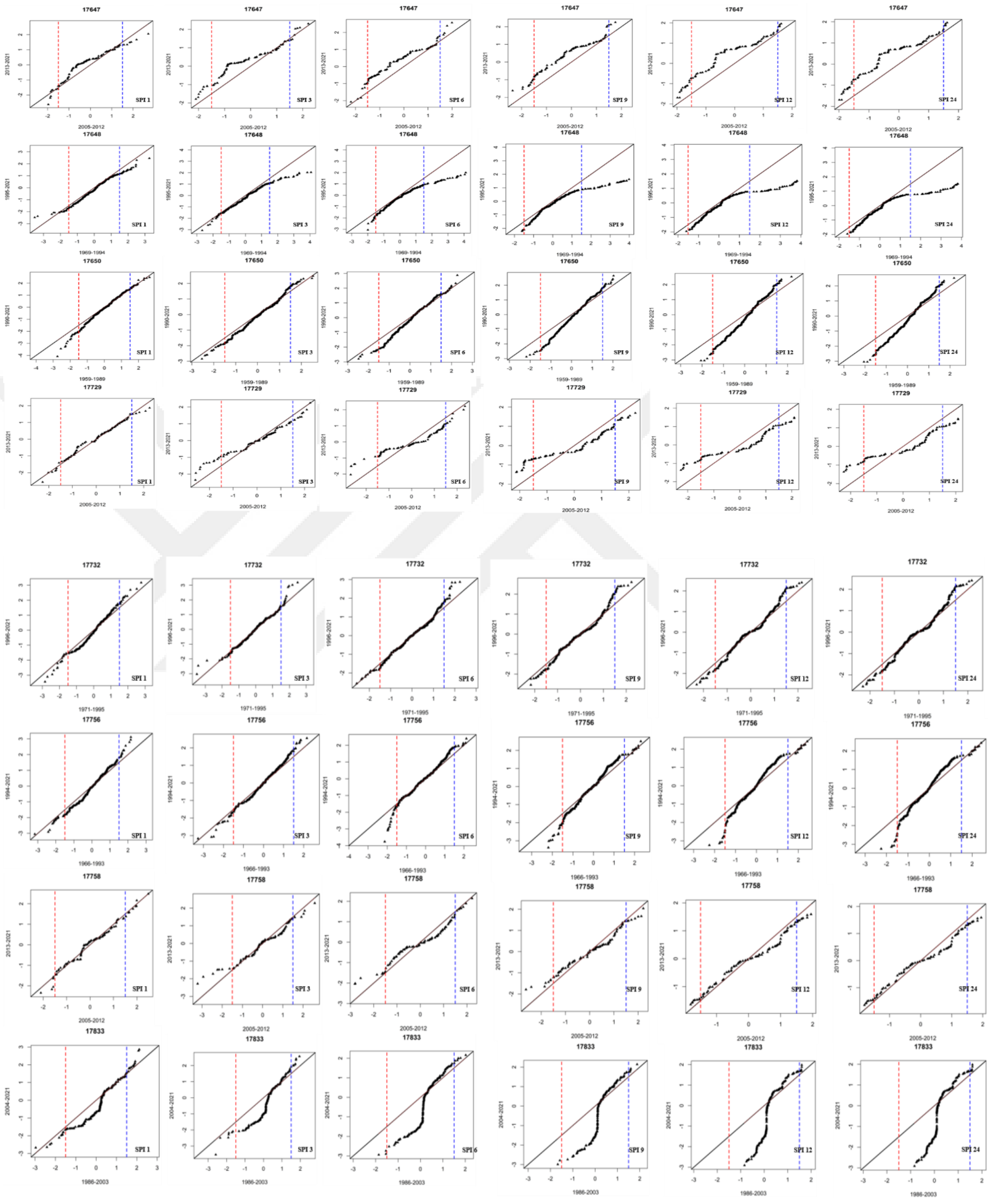
Station	SPI-1		SPI-3		SPI-6		SPI-9		SPI-12		SPI-24	
	Dry	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**	**Dry**	**Wet**
17074	77	56	65	44	72	48	65	45	70	46	58	41
17135	54	39	60	41	45	48	44	50	53	57	25	46
17137	14	11	12	15	16	13	17	12	16	12	26	9
17160	73	61	73	59	76	57	78	60	80	60	67	58
17193	52	39	62	45	52	43	54	45	61	52	50	39
17196	63	68	55	64	59	58	51	66	55	71	38	87
17618	44	31	41	29	36	33	42	36	43	28	40	38
17620	16	11	18	3	14	4	15	7	15	5	9	14
17647	17	11	12	14	11	12	13	8	17	11	11	5
17648	54	35	42	38	30	37	21	36	12	38	11	45
17650	56	45	59	53	54	50	54	42	48	40	48	48
17729	14	9	16	13	9	10	16	11	12	10	14	17
17732	37	35	40	38	41	37	42	41	41	43	46	37
17756	46	35	49	39	47	35	41	38	42	42	41	49
17758	11	15	12	9	14	14	12	11	11	13	13	10
17833	33	30	41	22	47	23	49	17	46	23	57	13
17836	46	42	42	38	47	31	46	34	53	36	46	46
Total	**707**	**573**	**699**	**564**	**670**	**553**	**660**	**559**	**675**	**587**	**600**	**602**

Appendix B.

ITA Analysis Results of each station 1-, 3-, 6-, 9-, 12-, and 24-month time scale.



ITA Analysis Results of each station 1-, 3-, 6-, 9-, 12-, and 24-month time scale. (Cont.)



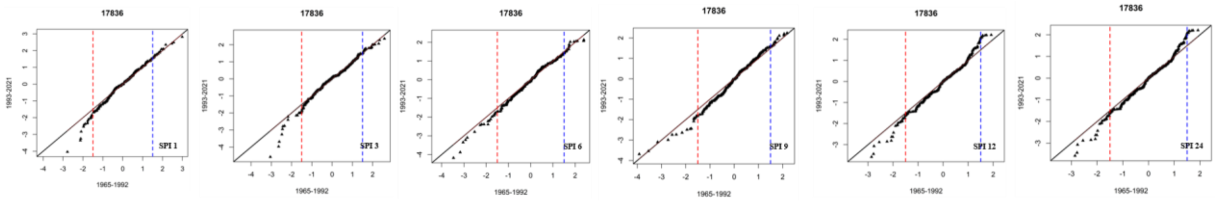


Figure B.1 ITA Analysis Results of each station 1-, 3-, 6-, 9-, 12-, and 24-month time scale.

Appendix C.

Table C.1 Mann-Kendall test results for station 17074.

Mann-Kendall trend test

	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
z	2.8297	6.1841	9.1812	10.601	11.341	14.377
n	1069	1069	1069	1069	1069	1069
p-value	0.004659	6.25E-10	< 2.2E-16	< 2.2E-16	< 2.2E-16	< 2.2E-16
s	32991	72099	107041	123597	132215	167613
var	135921839	1.36E+08	1.36E+08	1.36E+08	1.36E+08	1.36E+08
tau	0.05787652	0.126487	0.187768	0.216814	0.231959	0.294047

Table C.2 Mann-Kendall test results for station 17135.

Mann-Kendall trend test

	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
z	-0.19357	0.46034	0.96281	1.1253	1.5495	2.7024
n	685	685	685	685	685	685
p-value	0.8465	0.6453	0.3356	0.2605	0.1213	0.006884
s	-1159	2755	5761	6733	9271	16168
var	35790078	35790209	35790360	35790249	35790235	35790188
tau	-0.00495	0.011777	0.024624	0.028781	0.03963011	0.069117

Table C.3 Mann-Kendall test results for station 17137.

Mann-Kendall trend test

	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
z	0.60859	0.65399	0.36933	0.3632	1.162	3.6369
n	181	181	181	181	181	181
p-value	0.5428	0.5131	0.7119	0.7165	0.2452	0.000276
s	497	534	302	297	948	2965
var	664232.3	664230	664191.3	664180.3	664211.3	664201.7
tau	0.030542	0.032819	0.018569	0.018273	0.058288	0.182322

Table C.4 Mann-Kendall test results for station 17160.

Mann-Kendall trend test

	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
z	-0.43825	-0.11842	-0.48703	-1.2526	-1.7594	-1.8808
n	973	973	973	973	973	973
p-value	0.6612	0.9057	0.6262	0.2104	0.07851	0.06
s	-4438	-1200	-4932	-12683	-17814	-19043
var	1.03E+08	1.03E+08	1.03E+08	1.03E+08	1.03E+08	1.03E+08
tau	-0.0094	-0.00254	-0.01044	-0.02686	-0.03773	-0.04033

Table C.5 Mann-Kendall test results for station 17193.

Mann-Kendall trend test

	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
z	0.99601	0.8454	0.81927	0.84555	0.80357	1.9878
n	733	733	733	733	733	733
p-value	0.3192	0.3979	0.4126	0.3978	0.4216	0.04683
s	6596	5599	5426	5600	5322	13164
var	43843595	43847391	43847369	43847417	43847393	43847445
tau	0.024643	0.0209	0.020254	0.020903	0.019866	0.049136

Table C.6 Mann-Kendall test results for station 17196.

Mann-Kendall trend test

	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
z	2.7045	4.6285	6.9819	8.3525	9.5185	12.517
n	973	973	973	973	973	973
p-value	0.00684	3.68E-06	2.91E-12	< 2.2E-16	< 2.2E-16	< 2.2E-16
s	27383	46863	70690	84567	96372	126727
var	102504958	1.03E+08	1.03E+08	1.03E+08	1.03E+08	102507003.7
tau	0.05800908	0.099244	0.149695	0.179087	0.2041	0.2683842

Table C.7 Mann-Kendall test results for station 17618.

Mann-Kendall trend test

	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
z	-1.3604	-1.223	-1.1687	-1.0538	-1.0833	0.18603
n	517	517	517	517	517	517
p-value	0.1737	0.2213	0.2425	0.292	0.2787	0.8524
s	-5339	-4800	-4587	-4136	-4252	731
var	15397661	15398111	15398124	15398145	15398205	15398152
tau	-0.0401	-0.03604	-0.03444	-0.03105	-0.03192	0.005488

Table C.8 Mann-Kendall test results for station 17620.

Mann-Kendall trend test

	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
z	-0.37301	-0.52271	-1.3632	-1.6258	-1.8049	-1.5239
n	181	181	181	181	181	181
p-value	0.7091	0.6012	0.1728	0.104	0.07109	0.1275
s	-305	-427	-1112	-1326	-1472	-1243
var	664217.7	664199.7	664214.7	664233.3	664220.7	664221
tau	-0.01875	-0.02626	-0.06836	-0.08148	-0.09049	-0.07641

Table C.9 Mann-Kendall test results for station 17647.

Mann-Kendall trend test

	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
z	0.55092	0.15215	-0.35705	-0.37914	-0.18651	1.3202
n	181	181	181	181	181	181
p-value	0.5817	0.8791	0.7211	0.7046	0.852	0.1868
s	450	125	-292	-310	-153	1077
var	664232.667	664214.3	664226	664222.7	664195.7	664226.3
tau	0.02765488	0.007685	-0.01795	-0.01906	-0.00941	0.066193

Table C.10 Mann-Kendall test results for station 17648.

Mann-Kendall trend test

	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
z	-2.9255	-4.3124	-5.3195	-5.5403	-5.7701	-5.964
n	613	613	613	613	613	613
p-value	0.003439	1.62E-05	1.04E-07	3.02E-08	7.93E-09	2.46E-09
s	-14819	-21844	-26945	-28063	-29227	-30209
var	25655499.67	25655516	25655336	25655170	25655413	25655191
tau	-0.07913036	-0.11664	-0.14389	-0.14988	-0.15609	-0.16138

Table C.11 Mann-Kendall test results for station 17650.

Mann-Kendall trend test

	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
z	-0.66735	-0.95836	-1.5105	-1.9226	-2.0655	-1.2802
n	733	733	733	733	733	733
p-value	0.5045	0.3379	0.1309	0.05453	0.03888	0.2005
s	-4420	-6347	-10003	-12732	-13678	-8478
var	43847141	43847316	43847370	43847458	43847402	43847247
tau	-0.0165	-0.02369	-0.03734	-0.04752	-0.05106	-0.03165

Table C.12 Mann-Kendall test results for station 17729.

Mann-Kendall trend test

	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
z	0.35706	-0.38528	-0.99019	-1.1264	-1.281	-0.26871
n	181	181	181	181	181	181
p-value	0.721	0.7	0.3221	0.26	0.2002	0.7882
s	292	-315	-808	-919	-1045	-220
var	664221.3	664224.3	664214	664223	664225	664228
tau	0.017949	-0.01936	-0.04967	-0.05649	-0.06423	-0.01352

Table C.13 Mann-Kendall test results for station 17732.

Mann-Kendall trend test

	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
z	-0.80489	-0.42215	-0.74787	-0.85121	-0.55231	-0.25111
n	589	589	589	589	589	589
p-value	0.4209	0.6729	0.4545	0.3947	0.5807	0.8017
s	-3841	-2015	-3569	-4062	-2636	-1199
var	22760657	22760919	22761131	22761074	22761014	22760797
tau	-0.02222	-0.01165	-0.02064	-0.02349	-0.01524	-0.00693

Table C.14 Mann-Kendall test results for station 17756.

Mann-Kendall trend test

	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
z	-1.1726	-1.1047	-1.1489	-1.2899	-1.4275	-1.59
n	649	649	649	649	649	649
p-value	0.2409	0.2693	0.2506	0.1971	0.1534	0.1118
s	-6471	-6096	-6340	-7118	-7877	-8774
var	30442123	30442371	30442434	30442385	30442506	30442207
tau	-0.03082	-0.02903	-0.03019	-0.0339	-0.03751	-0.04179

Table C.15 Mann-Kendall test results for station 17758.

Mann-Kendall trend test

	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
z	-0.79635	-1.5411	-1.9988	-1.8687	-1.4957	-0.16196
n	181	181	181	181	181	181
p-value	0.4258	0.1233	0.04563	0.06166	0.1347	0.8713
s	-650	-1257	-1630	-1524	-1220	-133
var	664178	664231	664220	664222	664223.3	664221
tau	-0.03999	-0.07725	-0.10019	-0.09368	-0.07499	-0.00818

Table C.16 Mann-Kendall test results for station 17833.

Mann-Kendall trend test

	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
z	-4.6804	-6.4616	-7.3434	-7.3197	-7.6116	-8.3532
n	409	409	409	409	409	409
p-value	2.86E-06	1.04E-10	2.083E-13	2.49E-13	2.71E-14	< 2.2E-16
s	-12928	-17848	-20283	-20217	-21024	-23073
var	7628347	7628678	7628369	7627812	7628483	7628995
tau	-0.15546	-0.21444	-0.2438091	-0.24314	-0.2527	-0.2772256

Table C.17 Mann-Kendall test results for station 17836.

Mann-Kendall trend test

	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-24
z	-0.68982	-0.84093	-0.98729	-1.2694	-1.6648	-3.4114
n	661	661	661	661	661	661
p-value	0.4903	0.4004	0.3235	0.2043	0.09596	0.000646
s	-3913	-4770	-5600	-7200	-9442	-19347
var	32160286	32161119	32161079	32161108	32161091	32160898
tau	-0.01797	-0.0219	-0.02571	-0.03306	-0.04335	-0.08884

Appendix D.

Table D.1 Percentages of dry and wet classes in station 17193

Dry/wet Classification	SPI Class	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24
MD	(-0.99, 0)	26.7	33.2	32.7	31.2	31.1	28.2
MOD	(-1.49, 1)	10.3	6.6	8.5	9.3	8.1	10.2
SD	(-1.99, -1.5)	3.6	5.6	3.8	4.5	5.0	3.0
ED	≤-2	3.3	2.9	3.8	3.7	4.6	6.7
Wet	≥0	56.1	51.7	51.2	51.3	51.2	51.9

Table D.2 Percentages of dry and wet classes in Station 17196

Dry/wet Classification	SPI Class	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24
MD	(-0.99, 0)	33.5	38.1	32.7	32.5	34.8	37.0
MOD	(-1.49, 1)	8.3	7.8	10.4	11.4	9.8	11.5
SD	(-1.99, -1.5)	3.5	3.0	4.0	3.3	4.3	2.9
ED	≤-2	2.9	2.9	2.4	2.7	2.3	3.2
Wet	≥0	51.7	48.2	50.4	50.0	48.7	45.3

Table D.3 Percentages of dry and wet classes in station 17618

Dry/wet Classification	SPI Class	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24
MD	(-0.99, 0)	28.7	31.1	31.3	31.7	31.3	32.6
MOD	(-1.49, 1)	8.1	6.5	8.5	9.1	8.9	6.7
SD	(-1.99, -1.5)	5.0	3.9	2.8	4.6	5.2	4.8
ED	≤-2	3.1	4.1	5.0	4.8	4.8	7.2
Wet	≥0	55.0	54.4	52.4	49.8	49.8	48.7

Table D.4 Percentages of dry and wet classes in station 17620

Dry/wet Classification	SPI Class	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24
MD	(-0.99, 0)	26.0	27.9	28.9	32.4	27.9	23.0
MOD	(-1.49, 1)	6.9	3.4	6.4	6.4	9.3	15.2
SD	(-1.99, -1.5)	4.9	5.4	2.0	2.9	5.4	4.4
ED	≤-2	3.4	4.9	7.4	8.3	7.8	11.3
Wet	≥0	58.8	58.3	55.4	50.0	49.5	46.1

Table D.5 Percentages of dry and wet classes in station 17647

Dry/wet Classification	SPI Class	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24
MD	(-0.99, 0)	27.5	28.9	29.4	28.4	26.5	20.6
MOD	(-1.49, 1)	10.8	12.7	13.2	11.8	9.8	11.8
SD	(-1.99, -1.5)	6.9	4.9	4.9	6.4	8.3	2.9
ED	≤-2	1.5	2.0	3.4	4.4	5.4	14.7
Wet	≥0	53.4	51.5	49.0	49.0	50.0	50.0

Table D.6 Percentages of dry and wet classes in station 17648

Dry/wet Classification	SPI Class	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24
MD	(-0.99, 0)	29.7	31.6	38.1	38.5	41.4	50.2
MOD	(-1.49, 1)	6.8	9.4	8.5	10.1	10.5	6.3
SD	(-1.99, -1.5)	5.5	5.0	3.8	2.8	1.9	1.9
ED	≤-2	3.1	2.0	1.7	1.9	1.7	3.6
Wet	≥0	54.9	51.9	48.0	46.7	44.5	38.1

Table D.7 Percentages of dry and wet classes in station 17650

Dry/wet Classification	SPI Class	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24
MD	(-0.99, 0)	29.9	29.9	33.7	33.3	31.5	33.2
MOD	(-1.49, 1)	7.8	9.5	7.9	8.9	9.1	6.9
SD	(-1.99, -1.5)	3.6	5.2	4.0	4.0	3.4	3.0
ED	≤-2	3.8	2.9	4.0	4.4	4.5	6.5
Wet	≥0	54.9	52.5	50.4	49.5	51.5	50.4

Table D.8 Percentages of dry and wet classes in station 17729

Dry/wet Classification	SPI Class	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24
MD	(-0.99, 0)	25.5	29.4	38.7	31.4	30.9	27.5
MOD	(-1.49, 1)	9.8	8.3	9.3	7.8	9.8	6.9
SD	(-1.99, -1.5)	4.9	3.9	1.5	7.4	2.9	2.9
ED	≤-2	2.0	4.9	5.9	4.9	8.8	15.2
Wet	≥0	57.8	53.4	44.6	48.5	47.5	47.5

Table D.9 Percentages of dry and wet classes in station 17732

Dry/wet Classification	SPI Class	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24
MD	(-0.99, 0)	28.4	33.3	31.5	32.7	36.6	30.1
MOD	(-1.49, 1)	10.8	9.3	10.1	10.1	7.2	7.4
SD	(-1.99, -1.5)	3.4	4.6	5.1	4.7	4.2	4.9
ED	≤-2	2.9	2.5	2.8	3.4	4.4	6.7
Wet	≥0	54.4	50.3	50.5	49.0	47.5	51.0

Table D.10 Percentages of dry and wet classes in station 17756

Dry/wet Classification	SPI Class	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24
MD	(-0.99, 0)	30.7	31.8	29.0	31.1	32.7	33.3
MOD	(-1.49, 1)	8.6	8.3	10.3	10.6	8.8	8.8
SD	(-1.99, -1.5)	3.7	4.2	5.1	3.4	4.5	3.9
ED	≤-2	3.4	3.4	2.8	3.9	3.9	5.7
Wet	≥0	53.6	52.2	52.8	51.0	50.1	48.4

Table D.11 Percentages of dry and wet classes in station 17758

Dry/wet Classification	SPI Class	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24
MD	(-0.99, 0)	33.3	30.9	31.4	26.0	28.9	26.0
MOD	(-1.49, 1)	9.8	9.3	9.3	12.3	14.7	11.3
SD	(-1.99, -1.5)	3.4	2.5	4.9	5.4	5.9	4.9
ED	≤-2	2.0	4.4	4.9	4.9	5.4	12.7
Wet	≥0	51.5	52.9	49.5	51.5	45.1	45.1

Table D.12 Percentages of dry and wet classes in station 17833

Dry/wet Classification	SPI Class	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24
MD	(-0.99, 0)	26.9	25.7	18.5	18.3	18.5	19.7
MOD	(-1.49, 1)	8.3	6.5	7.2	5.6	5.1	1.2
SD	(-1.99, -1.5)	6.0	6.3	6.3	6.5	5.6	6.7
ED	≤-2	2.1	3.7	5.8	6.7	8.3	11.8
Wet	≥0	56.7	57.9	62.3	63.0	62.5	60.6

Table D.13 Percentages of dry and wet classes in station 17836

Dry/wet Classification	SPI Class	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24
MD	(-0.99, 0)	28.2	33.3	33.2	29.2	27.0	30.8
MOD	(-1.49, 1)	9.4	7.7	6.9	8.6	8.6	10.1
SD	(-1.99, -1.5)	4.2	2.8	3.4	3.9	5.0	6.9
ED	≤-2	2.6	3.7	4.2	4.1	4.5	3.9
Wet	≥0	55.6	52.5	52.3	54.1	54.8	48.2

CURRICULUM VITAE

Name and surname: Hamza Barkad ROBLEH

EDUCATION

2024: Msc. Civil Engineering in Gaziantep University — Gaziantep, Turkey.

2020: C1 Turkish language in TÖMER « Teaching Turkish Application And Research Center. »

2019: Msc. Civil Engineering in Djibouti University — Djibouti

WORK EXPERIENCE

05/2017 – 06/2017: Internship as civil engineer in Siyahkalem Engineering Construction Industry and Trade Inc. — Sultan II Abdoulhamid mosque project – Djibouti.

07/2018 – 12/2018: Internship at Arkimed, consulting and design office.

LANGUAGE SKILLS

SOMALI: Mother tangue

ENGLISH: Advanced Level

TURKISH: Intermediate Level

FRENCH:Advanced Level

ARABIC: Intermediate Level