INVESTIGATION OF METEOROLOGICAL DROUGHT CHARACTERISTICS OF THE GREAT MAN-MADE RIVER REGION (LIBYA)

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I certify that in my opinion the thesis submitted by Mustafa Ibrahim Mohamed ELHAJ titled "INVESTIGATION OF METEOROLOGICAL DROUGHT CHARACTERISTICS OF THE GREAT MAN-MADE RIVER REGION (LIBYA)" is fully adequate in scope and quality as a thesis for the degree of Master of Science.

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“I declare that all the information within this thesis has been gathered and presented in accordance with academic regulations and ethical principles and I have according to the requirements of these regulations and principles cited all those which do not originate in this work as well.”

Mustafa Ibrahim Mohamed ELHAJ

ABSTRACT

M. Sc. Thesis

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In this study, located in the Great Man-Made River region, meteorological drought analysis were conducted for five monitoring stations in Northern Libya, the Standardized Precipitation Index (SPI) method and the Reconnaissance Drought Index (RDI) method were used to determine meteorological drought using monthly total precipitation data, and using mean monthly temperatures data and total monthly precipitation data, respectively. The drought analysis using DrinC software of the Great Man-Made River region for 1-, 3-, 6-, and 12-months SPI and RDI values were conducted and examined in detail. According to the SPI-12 month index values, the driest period was determined by 86% in Tripoli Airport and Nalut station, and the least dry period was determined at Sirt station by 39%, and as a result of the analyzes that were conducted, according to the values of the RDI-12 month index, the longest period was determined drought in Zuara station in the year 2000-2001. It was noted that the year 2000-2001 was one of the driest years of all stations, and the other years with high drought rates were 1981-1982, 1984-1985, and 1992-1993.

Key Words : Standardized Precipitation Index (SPI), Reconnaissance Drought Index (RDI), Meteorological Drought Analyses, The Great Man-Made River Region, Libya

Science Code : 91106

ÖZET

Yüksek Lisans Tezi

THE GREAT MAN-MADE RIVER BÖLGESININ (LİBYA) METEOROLOJİK KURAKLIK KARAKTERİSTİKLERİNİN İNCELENMESİ

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Büyük İnsan Yapımı Nehir Bölgesinde gerçekleştirilen bu çalışmada, Kuzey Libya'daki beş gözlem istasyonu için meteorolojik kuraklık analizleri yapılmış, meteorolojik kuraklığın belirlenmesi için, aylık toplam yağış verileri kullanılarak Standartlaştırılmış Yağış İndeksi (SPI) yöntemi ve ortalama aylık sıcaklık verileri ve toplam aylık yağış verilerinden yararlanılan Keşif Kuraklık İndeksi (RDI) yöntemi kullanılmıştır. Büyük İnsan Yapımı Nehir bölgesinin DrinC yazılımı kullanılarak 1-, 3-, 6- ve 12 aylık SPI ve RDI değerleri doğrultusunda kuraklık analizi gerçekleştirilmiş ve detaylı olarak incelenmiştir. SPI-12 aylık indeks değerlerine göre en yüksek kuraklığın gözlemlendiği dönem %86 ile Trablus Havalimanı ve Nalut istasyonu olup, en düşük kuraklığın gözlemlendiği dönem ise %39 ile Sirt istasyonu olmuş ve gerçekleştirilen analizler sonucunda, RDI-12 aylık indeks değerlerine göre en uzun süre 2000-2001 yıllarında Zuara istasyonunda yaşanan kuraklık olarak belirlenmiştir. 2000-2001 yılının tüm istasyonlar açısından en kurak yıllarından biri olduğu ve kuraklık oranlarının yüksek olduğu diğer yılların ise 1981-1982, 1984-1985 ve 1992-1993 yılları olduğu kaydedilmiştir.

Anahtar Kelimeler : Standart Yağış İndeksi (SPI), Keşif Kuraklık Endeksi (RDI), Meteorolojik Kuraklık Analizleri, The Great Man-Made River Bölgesi, Libya.

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SYMBOLS AND ABBREVIATIONS

SYMBOLS

Pij : Precipitation

σ : Standard deviation

Xi : Amount of precipitation

P : Speed deviation

Pi : The axis quantity

N : Total number of years of the available data.

$\bar{y}$: Arithmetic mean

αk : Values follow the lognormal distribution

Γ(γ) : Gamma function

γ,β : Shape and scale parameters

G(x) : Cumulative probability

q : Probability of zero precipitation

ABBREVIATIONS

ANN : Artificial Neural Networks

PNI : Percentage Normal Index

SPI : Standardized Precipitation Index

RDI : Reconnaissance Drought Index

EDI : Effective Drought Index

SDI : Streamflow Drought Index

PD : Precipitation Deciles

PET : Potential Evapotranspiration

PART 1

INTRODUCTION

1.1. AIM OF THE STUDY

The main purpose of this thesis study is to determine the drought sensitivity by making meteorological drought analyzes of The Great Man-Made River zone where was carried out within the scope of a study aiming to transmit the groundwater from various aquifer systems in the Southern Libyan region to the coastal regions through pipes. Furthermore this study aims to determine the longest-drought period in the study area. For the purpose this study, meteorological drought analysis will be conducted in the region, for five monitoring stations in Northern Libya.

1.2. PROBLEM STATEMENT

Drought is a pernicious natural hazard that involves a wide range of climatic processes and has far-reaching effects on both the environment and society. Due to the present harsh climatic occurrences, there has been an increase in interest in drought consequences and monitoring in recent years. These types of droughts have implications for many of the GEOSS (Global Earth Observation System of Systems) Societal Benefit Areas (SBAs), and this phenomenon set up an interconnection between various fields, such as agriculture sustainability, food security, ecosystem functions and services, biodiversity and carbon stocks, water resources, and wildfires. A drop in precipitation paired with rising temperatures associated with drought occurrences is predicted, particularly in the Mediterranean Basin, which would reduce water availability for natural and agricultural systems and human requirements, according to the newly released IPCC (Intergovernmental Panel on Climate Change) 5th Assessment Report [1]. The main concern is to find one of the driest years of all the stations and to find the years with high drought rates.

By making efficient use of the huge fresh water reservoirs in Libya's southern area, the GMMR project aims to raise the quality of life for its people. High salinity rates in the north and low groundwater levels have put the Great Man–Made River on the verge of collapse, where every meter of fresh water decreases and 40 meters of salt rise. In light of Libya's dwindling water supply and increasing population, it is more important than ever to seek foreign aid funding. Money might be used to build hydraulic equipment required to harvest and transport water from the desert for use in agriculture and consumption in heavily populated regions [2]. For these reasons the subject was chosen to study and analysis the longest-drought period to avoid any future problems.

Drought is a natural disaster with multiple varieties. According to the purpose of the study and the data used, many methods assessed drought and its development in various factors. Therefore, according to methods, developed by Palmer (1965) [3] to translate drought into the language of mathematics and Palmer Drought Severity Index (PDSI) based on precipitation and temperature data [4], and had analyzed solely of precipitation data Standardized Precipitation Index (SPI) which had explored meteorological drought [5]. Also, the Reconnaissance Drought Index (RDI) had analyzed during the compare and completion of the results.

1.3. GEOGRAPHY OF LIBYA

Libya is located in North Africa, on the Mediterranean Sea's coast. It has a border with Egypt on the east, Sudan, Chad, and Niger on the south, and Algeria and Tunisia on the west. Libya has a total landmass of 1759540 km^2. Worldometer's re-interpretation of the most recent United Nations population estimates put Libya's current population in 2021 at 6,994,744 [6].

The scorching, dry Sahara predominates in Libya's climate, while the Mediterranean Sea cools things down at the country's coast. Summer is when the Saharan impact is at its strongest. Winds from the west produce cyclonic storms and rain to northern Libya from October through March. A cold, wet winter and a hot, dry summer describe the Mediterranean climate along the shore. Benghazi and Tripoli see their highest temperatures in July and August. In addition to the hot, dry air from the south, there is also the ghibli wind, which sweeps across the whole nation several times a year. A brief respite in the prevailing winds occurs before the ghibli hits full force. Large amounts of sand dust are carried by the wind, causing the sky to become red and visibility to drop to less than 18 meters. a quick reduction in relative humidity increases the wind's heat, and this may happen in only a few hours [7].

The yearly rainfall in Libya varies from 100 mm in the south to 600 mm in the north. The coastal areas get the most rain, while the southern parts get as little as 10 millimeters. Only 5% of Libya receives more than 100 millimeters of rain each year. Libya has dry places where it never rains. The overall quantity of water available in 2012 is estimated at 3890 mm3 based on certain statistics. In 2012, an estimated 5830 mm3 of water was withdrawn. Of this total, 83% was used for agricultural, 13% was used for residential purposes, and 2% was used in the industrial sector (5 percent). The quantity of water used in 2012 was 1940 mm3 more than the amount of water available. Libya has a number of pressing issues, including a lack of clean water, which may worsen if no action is made soon. There are claims that Libya is one of the most water-stressed nations in the world, with a score of 4.84. It has consistently been rated as one of the world's most water-stressed regions. There has been no serious investment in the field of water desalination previously even though desalination plants have been in operation there since the 1960s, despite the fact that this alternative water supply technology has been proven and is becoming increasingly important worldwide. The man-made river project was the primary focus of the previous of the authorities efforts to give Libyans living in the north with access to potable water (MMRP). MMRP is one of the largest civil engineering projects, although it has failed to resolve Libya's water shortages [8].

Having access to clean water is critical for human survival and agricultural productivity in Libya's desert environment. Water quality has been harmed due to contamination from saltwater intrusion and oil drilling, and the available supply has shrunk. As a result, water quality is taken into account to be crucial. Man-made activities like oil drilling pollute the water in addition to natural reasons like increasing sea levels. Drilling methods like fracking, which are becoming more common, have exposed Libya's huge natural aquifers to toxins and chemicals, which has had a significant impact on the country's water supply. Libya's surface water resources are severely constrained; they account for less than 3% of the country's total water use. The water quality in most of the springs is rather excellent. Only a few, on the other hand, are unfit for consumption due to their salt levels. Dryland agricultural projects in southern Libya, as well as those in densely inhabited regions, have high nitrate concentrations, according to the findings. Contamination from agricultural operations, on the other hand, is still very infrequent [9].

1.4. DEFINITION OF DROUGHT

Drought is defined as a phenomenon that may be related to the area under investigation and should be addressed using a specific application. Drought cannot be used to measure a region's average rainfall over several years. As a result, the region faces environmental, economic, and social challenges. Drought is one of the many natural disasters that have occurred throughout the world. As a result, many definitions of the dangerous drought had been developed [10]. During a drought, a lack of moisture usually results in a severe hydrological imbalance. Because of this condition, drinking water is typically used for precipitation, which has serious consequences for both humans and the environment. The area had also experienced dry weather and long-term water scarcity as a result of water scarcity. According to Hagman (1984), drought is the most common natural disaster [11]. These are the most complex of all natural disasters that have affected man, but the nature of drought has been described as the event [12], in a specific period and specific circumstances; the decrease of water availability in the area is termed as drought. Every year, various regions of the world are affected by drought [13].

1.5. THE EFFECTS OF DROUGHT

Drought is a natural occurrence with numerous consequences. Economic, environmental, and social effects are all common. With the emergence of drought as a result of a lack of rainfall, the region's water and water resources, which were the source of life, decrease. It is also possible that agricultural productivity will suffer as a result. Consider our own country as an example, where the effects of drought and semi-arid climate characteristics are felt.

In this situation, some issues may arise as a result of the agricultural and hydrological drought, which occurred as a result of the country's meteorological drought, at a time when Libya has been experiencing a dry period. Certain agricultural sectors, which are among Libya's most important essential sectors, have suffered as a result of the agricultural drought. Similarly, the products cultivated by farmers, which are considered the most basic elements of this sector, are generally climate dependent. As a result, a decrease in rainfall usually resulted in problems such as a decrease in product yield and an inability to meet the country's food needs [14].

1.6. TYPES OF DROUGHTS

Considering the severity, duration, and effects of the drought, there are certain drought types; meteorological drought, agricultural drought, hydrological drought andsocioeconomic drought [15].

1.6.1. Meteorological Drought

Meteorological drought is defined by the severity and duration of the drought. Depending on rainfall data, it is the first type of drought we encounter. Because its effect is dependent on rainfall, the period of rainfall corresponds to a normal level in that drought type. Because the climate regime of the regions is an important factor, meteorological droughts vary in different locations. Taking two regions with different precipitation amounts as an example, the average annual rainfall in the first region is estimated to be 500 mm/year for longer years, while the annual rainfall in the second region is estimated to be around 1500 mm/year. If the amount of rainfall in the region in the same year is 750 mm/year, then the first region is experiencing a humid year, while the second region is experiencing a dry year. The main reason for this is due to atmospheric conditions that caused a lack of precipitation based on the climatic regime. Furthermore, meteorological drought had recorded monthly rainfall data. It is assessed on a seasonal, water-year, and annual time scale [16]. As a result, the researcher observed the significant socioeconomic impact of such frequent changes.

1.6.2. Agricultural Drought

An agricultural drought is investigated as a result of a lack of rainfall due to meteorological drought and soil water deterioration. The water demand of a plant is determined by its biological properties, as well as the growth or stages of the soil's physical and biological properties [17]. During the agricultural drought, even plants that were thought to be able to meet their nutritional needs in the developmental stage suffered from flaws caused by insufficient subsoil moisture. The moisture in the soil has the potential to change the final product. The plant's yield is unaffected by incomplete development. Furthermore, if the lack of subsoil moisture persisted, a significant yield loss would occur. As a result, an important feature in agricultural drought triggered is the subsoil that plants require the most. The presence of moisture in the soil had played an important role during the plant's growth and development phase. As a result, in agricultural drought, monthly assessments are regarded as more important than annual assessments. Furthermore, agricultural drought is the most severe and widespread type of drought after meteorological drought. As a result, agriculture is the first sector to be affected by meteorological drought.

1.6.3. Hydrological Drought

A lack of water in the hydrological system was referred to as a hydrological drought. It was a type of drought in which water levels in rivers, lakes, reservoirs, and groundwater were unusually low [18]. The hydrological drought indicated that the total flow of the dry year was lower than the previous year's average flow. Furthermore, the frequency and severity of hydrological drought are typically defined at the river basin scale. A hydrological drought is considered to be ongoing if the actual flow in a river during a specified time period falls below a certain threshold. As a result, the effects of hydrological drought upstream of a river basin may reduce downstream flow and vice versa [18]. Although meteorological drought was not studied in this part of the basin, it would eventually result in lower reservoir and groundwater levels at downstream locations, particularly at the basin's bottom. As a result, decreases in reservoir and groundwater levels in certain parts of the city may have serious consequences for public water resources, hydroelectric power generation, recreation, transportation, agriculture, and other sectors. Furthermore, because it was thought to be a time-consuming process to fill reservoirs and groundwater, hydrological drought could last for months or years [18]. For example, after years of severe drought in a river basin, many years of normal rainfall were required to replenish the reservoirs.

1.6.4. Socioeconomic Drought

The socioeconomic drought occurred as a result of meteorological, hydrological, and agricultural drought factors being linked to the supply and demand for certain economic goods or services. Water, food, and hydroelectric energy supply, for example, are all affected by weather conditions. In most cases, demand for these goods is increasing as a result of rising per capita consumption. As a result, droughts are typically caused by an increase in demand for supply goods and a decrease in climate factors [18].

PART 2

LITERATURE REVIEW

2.1. PREVIOUS STUDIES

An attempt is made in the study of Aksoy vd. (2018), for the drought analysis with the SPI method using the data of 35 stations in the Gediz Basin with at least ten years of measurement between 1960 and 2016. As a result of the study, they had determined the SPI values for the periods of 1, 3, 6, 12, 24 and 48 months. For all periods in the basin, they found that 32% of the time had a mild drought, 8.8% moderate drought, 5% severe drought, and 2.3% of severe intensive drought [19].

A study by Al-Faraj and Al-Dabbag [20] looked at the impact of a multi-year drought on the growth of the Diyala River basin, which is shared by Iraq and Iran.

Al-Qinna et al. (2011) [21], Standardized Precipitation Index and Normalized Difference Vegetation Index methods, a detailed exploration of average day to day temperature and metrological drought analysis of the Hashemite Kingdom of Jordan between 1970-2005 was conducted. According to the results of these two indices, an extraordinary extreme drought was observed in the period 1999-2000 and it was stated that the country was exposed to drought cycles for 35 years after on. In addition, with the Standardized Precipitation Index method, predictions were made until 30 years the local would remain victimized to extensive drought conditions.

Al-Timimi and AL-Jboori (2013) conducted a drought analysis in the Iraq Region (SPI) method. Among the stations they studied, Dohuk, Sulaymaniyah, Dokan and Erbil stations were more affected by drought and the drought size in the 1999-2000 season varied between (18.4 and 17.4) mm. The northeastern region of Iraq faced high drought during 1980-2012. 1983, 1998, 1999, 2000 and 2008 are the years most affected by drought [22].

According to the SPI drought index, the Euphrates-Tigris basin in the Middle East just underwent a recent drought study [23].

Moreover, Apak (2009) [24], his research study has analyzed the drought origins in stations with long-term rainfall measurement in the Aegean Region by using the Standard Precipitation Index method for two periods, 1938-1970 and 1971-2006. As a result of these analyzes, he mentioned the effectiveness of the investigation in two periods in determining the severity of the drought and observed that in the second period both the number of dry years and the drought intensity increased as compared to the first.

Arslan et al. (2016) [25], investigated the droughts that occurred in the Gediz Basin between these years by using the Standard Precipitation Index (SPI) for 1,3,6,9,12 and 60-month periods, using the monthly precipitation data of 8 meteorological precipitation stations between 1973 and 2013. As a result of the study, it was determined that the droughts experienced in recent years lasted longer. For periods of 12 and 60 months. It has been stated that the drought period has increased by 3-7 times in recent years compared to the past.

Drought assessment in Urmia Lake basin was attempted using the Standardized Precipitation Index approach. Aslı and Hezerani (2019). They found that short-term scales react fast to changes in precipitation, whereas long-term scales are more likely to be affected by drought. SPIs are said to be most affected by monthly precipitation, which has a significant impact on total quarterly precipitation. As a result, the length of droughts in long-term series was shown to be longer than in short-term series [26].

Atmaca (2011) [27], analyzed the drought of Konya's region with the L-moments approach and utilized the methods of Standard Precipitation Index method. In his study, he created 3, 6, 9 and 12-month cumulative rainfall series using the monthly precipitation; he had obtained from the stations in the province. When he divided 44 observation stations into three regions, he was able to achieve homogeneity and as a result, he observed that mild drought was common in the regions according to SPI values.

Meteorological drought study in Northern Iraq was undertaken by Awchi and Kalyana (2017) utilizing the Standardized Precipitation Index (SPI) and Geographic Information Systems (GIS) techniques. Meteorological drought was studied using the standardized precipitation index (SPI) at various time intervals (3, 6, 12, and 24 months). A total of nine meteorological stations in the research region were utilized to gather monthly precipitation data from 1937 to 2010. A geographic information system (GIS) was used to map the spread of drought in the research region at various time intervals. Since 1997–2001 and 2006–2010, the research region has seen the most severe drought periods in terms of frequency and severity. A moderate drought is being classified using the Drought SPI categorization system. Another conclusion was drawn based on the duration of the eastern drought period seen in the research area: There were several severe droughts in the area during the time [28].

Bakanoğulları (2020) used SPEI (Standardized Precipitation Evapotranspiration Index) and SPI Indices to analyze droughts in the Istanbul-Damlca Stream Basin. When determining drought frequency and severity in the study, researchers used the (SPEI) and (SPI). The Thornthwaite technique was used to determine the SPEI drought index evapotranspiration in the basin between 1982 and 2006, using meteorological data. It is statistically noteworthy that the coefficient of determination (R^2) between the yearly SPEI and SPI indices (0.977) is substantial. Drought patterns differed across the one, three, and six-month time frames, however. Study findings show a more accurate SPEI Drought Index when it comes to agricultural productivity and its usage is healthier [29].

Balcı (1992) [30], examined the drought situation of Salihli, Akhisar, Manisa and Menemen in the Gediz Basin using the Thorn Thwaite method within the scope of his master's thesis. In his study, he used monthly and annual data between 1931-1989. As a result, he revealed the years in which drought problems were encountered in various places. Therefore, he examined, and found that the dry period lasted at least four months and at most six months for the Gediz Basin.

Bossy et al. (1998) described the drought in Hungary using the SPI method and observed that the SPI index is suitable for measuring different types of drought [31].

Çaldağ et al. (2004) made a drought analysis for the Thrace Region (SPI) using the method. As a result, severe drought conditions were detected in most of the studied stations and the most severe drought years were found in 2000 and 2001 [32].

In a research by Coşkun (2020), a long-term precipitation trend analysis in the Van Lake basin was performed. The long-term recorded precipitation data from Van-Bölge, Muradiye, Erçiş, Gevaş, zalp, Tatvan, and Ahlat meteorological stations were used to evaluate both yearly and seasonal patterns in precipitation. Gevaş and Ahlat stations have shown a decline in yearly precipitation since the MannKendall Test, Spearman's Rho, and en Tests were used to analyze the data. Van-District station had an increase in annual precipitation, however this time the rise was negligible. Erciş and Ahlat stations have had a considerable fall in precipitation, whereas Van-Region has seen a little rise [33].

Dai [34] claimed that the atmospheric demand for moisture has grown as a result of the present warming and that this has likely altered the atmospheric circulation patterns, which has contributed to dryness.

Doğan (2013) [35], "Konya Closed Basin Drought Characterization had compared six different drought indices that were widely used in the world within the scope of his doctoral dissertation named "Temporal-Spatial Analysis of Konya Closed Basin". These included; Normal Precipitation Percentage (PNI), Precipitation Tails (YK), Z-Score, Chinese Z Index (ÇZI), Standardized Precipitation Index (SPI) and Effective Drought Index (EKI). Later, he made the drought analysis of Konya Closed Basin for the years 1972-2009, with drought indices, successfully determined the variabilities. Most effective basin stated that the drought, which was considered severe, was seen between the years 1973-1974, and the most drought events were between the periods 1996-2000.

Dupigny-Giroux. (2001) considers the SPI drought profile to be better than moisture indices and Modified Palmer. It works in small to medium time intervals [36].

Numerous studies have examined the effects of meteorological drought on a global, regional, and local level. This approach was developed by Dutra et al. [37] and is based on probabilistic predictions from the European Centre for Medium-Range Weather Forecasts (ECMWF).

Edossa et al. (2010) conducted a drought analysis for the Awash River Basin in Ethiopia. With the Standard Precipitation Index method, 30 precipitation stations between 1987 and 2000 were used to determine the 3, 6, and 12-month SPI timeline. He determined that the most severe drought periods in the basin were between May 1988 - June 1988 and April 1998 - May 1998 [38].

Efe ve Özgür, (2015) [39], have conducted a drought analysis of Konya and its Vicinity. In the study, drought analysis was made by using the monthly total rainfall data of 20 stations between the time periods of 1972-2013. They evaluated the results they found during both indices, in the month of April and August. The whole procedure was viewed on an annual basis. According to the SPI method, it was observed that 2013 was dry at all stations except only one station. They emphasized that such uniformity could not be mentioned according to the PNI method.

Eklund and Seaquist [40] used the improved vegetation index (EVI) to study agricultural drought in Iraqi Kurdistan. Over the region, they found that precipitation decreased by around 50%, resulting in a 62% reduction in vegetative cover in 2008.

Drought frequency and severity in the eastern Mediterranean have shifted since 2008, according to Gleick [41].

Gümüş (2017) used the Stream Arid Index approach to conduct drought studies in the Asi Basin. Data from four flow monitoring sites between 1954 and 2005 were analyzed in the research. In the basin, the flow drought index calculations for the 3, 6, and 12-month time series indicated the dry, humid, and wet times of year. There were many more broken years between 1980 and 2005 than in prior years, according to the statistics. In addition, 2000 and 2001 were shown to be very dry years [42].

Gümüş and Algin (2017) conducted a drought analysis using (SPI) in their study for the Seyhan-Ceyhan river basins. Meteorological and hydrological drought analyzes were carried out in 3, 6 and 12 month time periods from the data obtained from 12 meteorology and 12 hydrology stations, and drought periods and drought severity were determined at different time periods in all stations [43].

Hayes et al. (1999) studied the advantages and disadvantages of using SPI for drought severity traits. Due to the simplicity of the calculations, SPI is capable of calculating for any desired period as the most suitable indicator for monitoring meteorological drought. Positive values of the SPI index indicate that precipitation is more than the average precipitation amount, and negative values have the opposite meaning. When the SPI is persistently negative and drops to -1 or below, it is considered to be in a drought and should be corrected. A drought's length and severity may be gauged using SPI values, which are calculated by subtracting positive numbers from negative ones [44].

Droughts in the Mediterranean area were examined using global climate models in a research by Hoerling et al. [45]. While 1902–1970 was a time of widespread wetness, 1971–2010 was marked by widespread drying conditions. Researchers discovered that the frequency of droughts has risen since 1970, and that cold-season precipitation in the Mediterranean area has been drier during 1902–2010.

Ilgar (2010) [46], made a 12-month (annual) and 3-month (seasonal) drought analysis by using the monthly precipitation totals observed at Çanakkale Central Meteorology Station between 1929 and 2007 using the SPI method. According to the results of the study, in Çanakkale an increase was observed in annual drought conditions. According to the results of seasonal drought analysis, an increase in drought was observed in winter, whereas a decreasing trend in drought in spring was also examined. In the summer and autumn seasons, a not so obvious increase trend was observed in drought.

Karabulut (2015) tried to determine the drought in Antakya - Kahramanmaraş. Long-term precipitation data of 4 meteorological stations in the Mediterranean were used to determine the Standard Precipitation Statistics (SPI) values. The time sets used were selected from 1975-2010. As a result, the four stations are heavily dependent on precipitation for their water supply [47].

Analysis of Upper Gediz Basin precipitation by Kumanlioglu and Fistikoglu (2019) was conducted. There were six separate meteorological sites where total precipitation data was collected and utilized in the Standardized Precipitation Index (SPI) drought index research. Between 1960 and 2017, a 58-year period was studied as a measuring period. Droughts experienced in the winter months have been shown to have a significant impact on the yearly droughts. This area has been experiencing more severe and long-lasting droughts recently, according to the data collected [48].

Lana et al (2001) used SPI to investigate deposition patterns in the Catalonia region of Spain. Consequently, some considerations must be made about the true meaning of lack and excess for the four seasons [49].

Climate change is expected to cause increasingly severe and frequent droughts in the Middle East, according to a research in the Eastern Mediterranean and the Middle East (EMME) by Lelieveld et al. [50]. Drought has lately hit Iraq, one of the Middle East's nations [51].

Lloyd-Hughes and Saundersa (2002) calculated SPI on a different time scale (between 1 and n months), and observed that SPI values (2-3 months time scale) could be used for agricultural drought. They found that the trend in SPI values represented a significant shift in severe or moderate drought rates in Europe during the twentieth century [52].

Loukas et al. (2003) used Z number, precipitation anomaly and three indicators of standard sediments to investigate meteorological droughts at different time scales in Greece. They concluded that the three indicators for the 21-month time frame had the same trend and also had good agreement with Palmer's index (PDMS) [53].

Masarie and Tans (1995) [54]. discussed that the drought analysis of Karaman province using SPI, RDI (Reconnaissance Drought Index) and EDI (Effective Drought Index). For this purpose, the monthly rain and precipitation were measured between 1975 and 2009at the Karaman meteorological station. They used the ETo (Reference plant water consumption) values determined according to the FAO56 Penman-Monteith relationship as material. Cumulative monthly rainfall for four different reference periods (k1, January-March; k2, January-June; k3, January-September; k4, January-December) and they obtained monthly ETo series and determined SPI, RDI and EDI Indices had shown that a dry period was started in Karaman in recent years.

McKee (1993) applied the SPI index for the first time in Colorado and found that the gamma distribution was the most suitable distribution for matching the sedimentation data, and defined drought and divided it into four different classes. In this study, they developed the Standard Precipitation Index (SPI), divided the data they used as input into 3, 6, 9, 12 and 48-month periods and compared them among themselves [55].

Merkoci et al. (2013) tried to find the 1, 3 and 6-month SPI values using the Standard Precipitation Index (SPI) in the Albanian region and used the data between 1951-2000. During the 1961-1970 and 1971-1980 periods, moderate, severe and extreme drought conditions occurred ten times (over a 10-year period). 2003 was the most notable year for drought, with southern Albania found to be extremely dry for SPI 6 values [56].

There has been an overall rise in severe occurrences over the last 25 years as a consequence of global warming, according to Mishra and Singh [57]. There are a wide variety of weather-related drought indicators in the literature.

Predicting the worldwide drought using SPI, Mo and Lyon [58] used the North American Multi-Model Ensemble (NMME). In another research, the Penman–Monteith potential evapotranspiration (sc PDSI pm) was combined with the self-calibrated Palmer drought severity index (sc PDSI pm) to investigate the scale and major causes of worldwide drought changes in the twenty-first century [59].

Oğuztürk (2010) [60], made a drought analysis with SPI in Gediz Basin within the scope of his master's thesis. He analyzed the drought characteristics of all stations by finding the SPI values of monthly precipitation data between 1950 and 2007, obtained from 14 meteorological observation stations in the basin. Later, he predicted the future drought by using Artificial Neural Networks (ANN) method. When he evaluated the 1-,3-,6-,9-,12- and 24-month SPI studies as a whole, he emphasized that drought events at various levels were frequently experienced in the basin due to the lack of rainfall and offered suggestions for a solution.

According to Özfidaner et al. (2018), the Seyhan Basin in Turkey has been experiencing a hydrological drought. The flow drought index (SDI) approach was utilized to analyze data from two separate flow stations. The monthly average and total flow statistics from 1967 to 2007 are included in the dataset. According to the index values derived from the three, six, nine, and twelve-month time series analyses, the 9-12-month reference periods at each stations were similarly analyzed. The Mediterranean's second six-month period may be dry, as a result, according to the findings. Additionally, it is claimed that long-term shift circumstances are related with a reduction in river flow [61].

Özgürel and Kılıç (2003) [62]. classified the annual precipitation in İzmir province in the period 1960-2001 according to the standardized precipitation index (SPI) system. At the end of the study, they stated that the most near-normal humid year occurred during this specific time frame.

The PDSI (Palmer Drought Severity Index) was proposed by Palmer (1965) and is based on the balance between water supply and demand. Afterwards, several researchers found that an index is simple to compute and statistically significant and meaningful. In addition, experts like McKee developed the SPI because they realized that a lack of precipitation had varied effects on groundwater, reservoir storage, soil moisture, snowpack, and streamflow [3].

Pamuk et al. (2004) determined drought in the Aegean region by using the (SPI) method. Precipitation values between 1971-2001 were used for 3, 6, 12, 24 and 48-month time periods. As a result, the results in this region in the rainy season were revealed. It has been determined that the coastal area is drier than the inner parts, and the inner western part of Anatolia is drier than the coastal area during the summer months [63].

Temperatures in Iraq have risen roughly 0.5 degrees Celsius every decade since 1995, according to another research by Robaa and Al-Barazanji [64].

Shafer and Dezman (1982) used the water level index for surface water assessment and this indicator is mostly used in mountainous regions. Also, blizzard height is one of the leading components of this indicator. The (SWSI) Index was designed for Colorado in 1982. (PDSI) index; It is a hydrological indicator designed to describe snow, water resources, river flow and rain fall at altitudes. Palmer drought index is a soil moisture algorithm. However, the SWSI indicator is designed to describe surface water conditions [65].

Among the 16 meteorological stations studied by Soliman (2020) are eight coastal stations, namely Agdabia, Benghazi; Derna; Misurata; Sirte; Tobruk; Tripoli; and Zwara. Ghadames, Ghariat, Hon, Jaghboub, and Jalo are desert stations, whereas Alfataiah, NALUT, and SHAHAT are mountain stations. The highest temperatures during the winter season exhibited no discernible patterns. In general, all stations except those around Green Mountain and Zwara station in the west have exhibited warming in the average maximum temperatures. Temperatures are warming at all locations except Shahat in the summer, according to the data. Temperatures rose at all sites throughout the spring, save for those at high elevations like Nalut and Ghadames [66]. During the spring and summer seasons, the western stations in the research region warm up, whereas Sirte, Agdabia, Jalo, and Hon stations cool down in the fall. Maximum temperatures did not change much during the course of the year. Except for those near Green Mountain and Zwara station in the west, all stations' maximum average temperatures have exhibited warming since the beginning of this century. In the summer, all stations except Shahat show warming in the lowest temperatures. There was a noticeable difference in temperature between the spring and fall seasons across all sites except those placed at a high altitude. At sites like Jagboub, Alfataiah, and Agdabia, as well as the yearly average, warming tendencies have been seen in the winter season and throughout the year. In average temperatures, the majority of stations exhibited a warming trend [66].

Soliman [66] study analysis the data for 40 years, from 1971 to 2010, except for Alfataiah Station (1981-2010) and Tobruk Station (1984-2010). Our study is using data between 1980-2009. Soliman [66] study used Microsoft Excel 2007 and IBM SPSS 23 program to organize the climate and other data and to create tables, graphs and figures for the data. Arc GIS 10.4 (Geography Information System) program was used to make the maps. This study used the Standardized Precipitation Index (SPI) method and the Reconnaissance Drought Index (RDI) method to determine meteorological drought using monthly total precipitation data, and using mean monthly temperatures data and total monthly precipitation data, respectively. For drought analysis DrinC software were used for 1-, 3-, 6-, and 12-months SPI and RDI values were conducted and examined in detail.

Stagge et al. (2015) used meteorological drought indexes to estimate the drought impact across Europe. Precipitation Evapotranspiration Index (SPEI) and Precipitation Index (SPI) were employed in the research. Five European nations' freshwater ecosystems and agriculture are both included in this study's four distinct effect categories. It is possible that agricultural impacts may be explained by anomalies of 2 to 12 months in length, and this is most likely a consequence of agricultural management techniques. It takes longer for hydropower and energy cooling water to have an influence on the energy and industrial sectors (6–12 months). A more complicated mix of short (1-3 months) and marine-sonal (6-12 months) aberrations are to blame for public water supply and freshwater ecological consequences. Because of their strong model fit (R^2 = 0.225-0.716) and predictive power, the derived drought impact models may be used to make educated guesses about the likelihood of drought effect on various ecosystems [67].

A study conducted by Şener and Şener (2019) to analysis meteorological dryness in the Çorak Lake basin by using a GIS-based temporal and spatial analysis. The standardized precipitation index (SPI) approach was used in the research to assess drought conditions. Between 1970 and 2016, which is the era in which this evaluation was carried out, the driest period occurred in 1989 and 1990, while the wettest period occurred in 2009, according to this study [68].

The Burdur Lake basin was studied by Şener and Şener (2020) to see if a drought was occurring. Two distinct techniques of drought analysis were used to compare the findings in this research. Six meteorological stations in and around the basin were utilized to gather precipitation data, which was analyzed using the SPI and the Chinese Z index (CZI). Using the SPI approach, it was found that the longest and most severe droughts at Burdur Meteorology Station had occurred since January 1951 and January 1989, respectively. Drought analysis utilizing the Chinese Z index revealed that the longest drought spells have been in effect since January 1989, according to the findings. It was found that the southern areas of the research region and near Burdur Lake were experiencing moderate and mild droughts in 2019. Drought index techniques employed have high R^2 values (0.96-0.98) and a statistically significant association between them [69].

Drought predictions for Konya province were created using artificial neural networks by Terzi and Ersoy (2018). For the province of Konya, long-term monthly average precipitation data from several meteorological stations was used using the standardized precipitation index (SPI) approach to analyze drought conditions. Drought categories for 3, 6, 9, and 12 months were identified, along with their percentage distributions and the stations' risk. It was utilized to simulate the predicted drought using an artificial neural network. For a 12-month period, the modeling analysis of several time series yielded the greatest coefficient of determination and the lowest mean square error value. The scientists found that drought forecasts may benefit from the artificial neural network technology [70].

Tonkaz and Çetin (2005) decided to determine the drought in Şanlıurfa in their study. They analyzed and determined their SPI values using monthly precipitation data collected from meteorological precipitation stations. Flow analysis was performed using the Mann-Kendall method. As a result, February, March, April were reported as severe short-term drought slices, and the successful Mann-Kendall statistics of the SPI series showed random behavior. It has been revealed that drought is frequently seen in January [71].

The Mediterranean and Central Anatolian regions would be the most hit by climate change, according to a report by Turan (2018). As indicated in the report, the drought dangers in our semi-arid nation have not yet been completely recognized and the most pressing issue will be a lack of water. Our country's drought is deemed a natural catastrophe, which necessitates the development of natural disaster legislation in order to safeguard the drought from its long-term impacts, according to reports [72].

Using monthly precipitation data from Wu and Hayes (2001), SPI, CZI, z-Score were evaluated on 1, 3, 6, and 9-month time scales for wet and arid climates of China. The researchers concluded that all three indicators gave the same results at all time intervals, but the calculations of the CZI and z numbers were more comfortable than the SPI index [73].

Yenigun and Ibrahim (2019) were able to analyze drought analysis (the length and intensity of drought) in the north Iraqi area during various time periods by employing the Standardized Precipitation Index (SPI). As a result of this characteristic, it is possible to compare drought experiences over a wide range of geographic and temporal dimensions. Monthly rainfall data from 15 meteorological stations in northern Iraq provinces were utilized from 1979 to 2013 to record dry and wet seasons, as well as the severity and duration of droughts. MATLAB software was used to do calculations on the SPI using the SPI code. Dry periods in the 6-, 9-, and 12-month time intervals were seen more than the 1- and 3-month intervals. According to the calculations, 2008 was the driest year [74].

According to Mosbah (1996), the policy of the Libyan government is aimed at achieving the greatest feasible rate of self-sufficiency and reducing dependency on foreign markets to the lowest possible level by expanding agricultural and animal output. This program also intends to boost the sector's capital investment and labor productivity while also generating raw materials for the food processing industry. When it comes to self-sufficiency, food security, and real independence, the river serves as a fresh lesson and an example to learn from [75].

PART 3

MATERIAL AND METHOD

3.1. INTRODUCTION

This chapter will first present the study methodology that used to collect and analyze the data of the study. Then general information about the study area and Great Man-Made River (GMMR) with manufacture of pipes and digging trenches and water transportation systems. Finally, the drought indices overview of the study.

The scope of the study is to check the drought sensitivity and calculate dry years to illustrate the driest years in the Great Man-Made River region with help of the data of 5 stations using the Standard Precipitation Index (SPI) and Reconnaissance Drought Index (RDI). In order to track changes in drought index values across time, drought analysis was used. Northern Libya has been selected for the research because of the scarcity of rainfall along the Libyan coast. Analyzes were carried out with the help of data between 1980 and 2009.

3.2. METHODOLOGY

This study, located in the Great Man-Made River region, meteorological and hydrological drought analysis will be conducted for five monitoring stations in Northern Libya, the Standardized Precipitation Index (SPI) method is used to determine meteorological drought using monthly total precipitation data, and the Reconnaissance Drought Index (RDI) method using mean monthly temperatures data and total monthly precipitation data. The drought analysis using DrinC software of the Great Man-Made River region for 1-, 3-, 6-, and 12-months SPI and RDI values is conducted and examined in detail.

3.3. STUDY AREA

This study aimed to determine drought sensitivity and calculate dry years to illustrate the driest years in the Great Man-Made River region using the Standard Precipitation Index (SPI) and Reconnaissance Drought Index (RDI) via the DrinC program in 5 meteorological stations using data between 1980-2009. Temporal changes of drought index values were examined with drought analysis. Northern Libya is the study area as rainfall is lack near the Libyan coast. Hence the study area is located between the longitudes of 9 and 25 easts and 30 and 33 latitudes of the north. The analysis is made through monitoring data from the stations based on the atmospheric droughts using the precipitations index of droughts as shown in the following given Table 3.1 and Figure 3.1 the rainfall monitoring stations and geographic information in northern Libyaused in the Great Man-Made River.

Table 3.1. Rainfall monitoring stations and its geographic locations.

Station Number	**Station Name**	**Coordinates and Altitudes**		
62007	Zuara	32.53 N	12.05 E	03 m
62010	Tripoli Airport	32.40 N	13.09 E	81 m
62002	Nalut	31.52 N	10.59 E	621 m
62016	Misurata	32,19 N	15.03 E	32 m
62019	Sirt	31.12 N	16.35 E	13 m

Figure 3.1. Northern Libya and locations of rainfall monitoring stations by Google Maps [76].

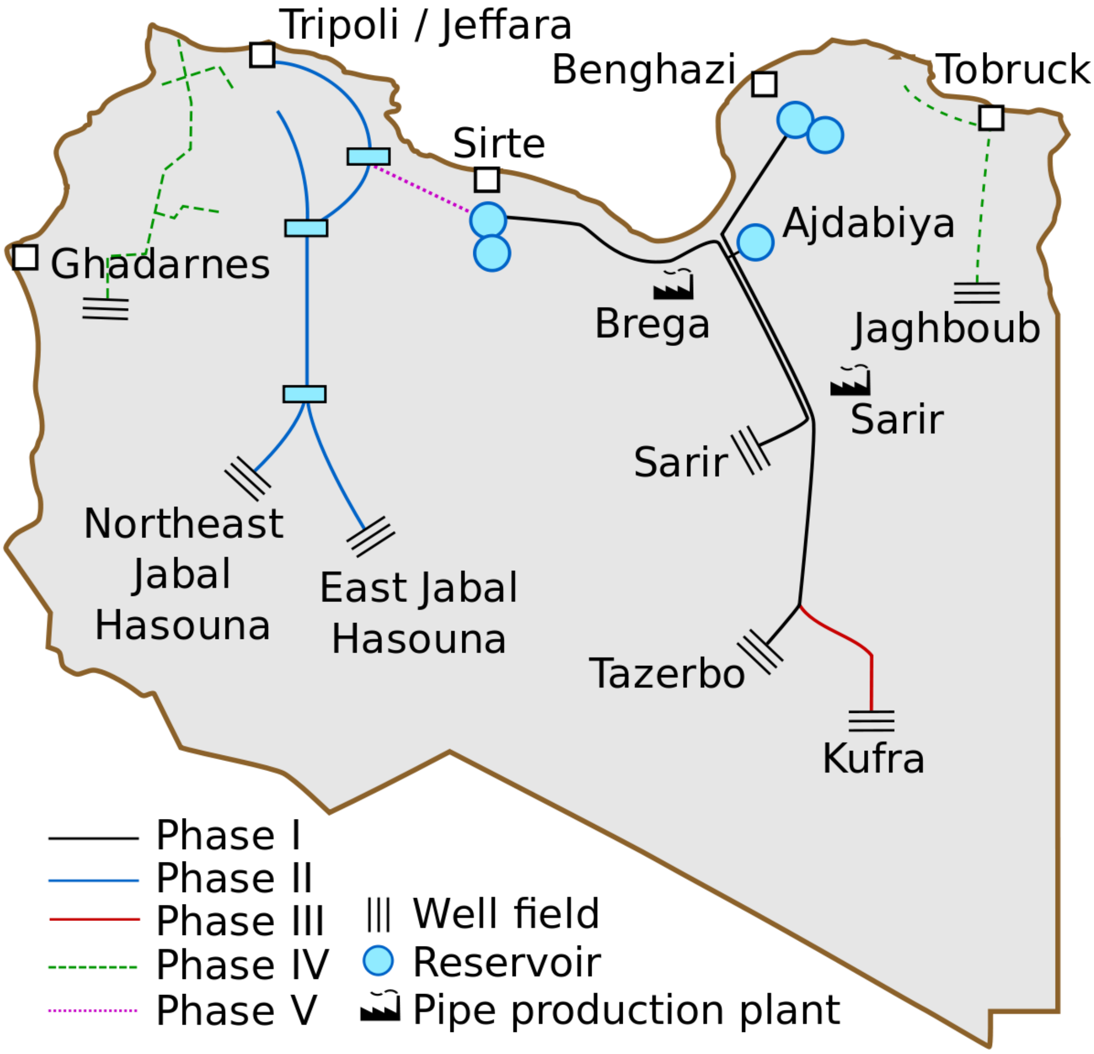

Figure 3.2. Schematic view of The Great Man-Made River Area [77].

3.4. GREAT MAN-MADE RIVER (GMMR)

Libya due to its appreciative and serious efforts which devoted to development and progress in a decisive challenge against various problems and obstacles, in particular the essential problem that remained the core conduct of an era was a scarcity of water resources. Since most of the Libya lands lay in arid regions and barely had any rainfall, which ultimately led to water shortage to farmlands, albeit theavailability of agricultural potentials. Hence the active factor in agriculture production is water and significant factors of lives for plants, soil and human [75]. The accelerated increase in population, the great industrial and agricultural progress and development in the northern parts of Libya, which in turn led to the consumption of watercaused serious shortage of local water resources and became reason for the deterioration of water quality. One of the reasons is due to seawater intrusion into the coastal water-bearing layers. This caused pollution and increased salinity of poTable water beside its negative effect on agriculture and land. The ultimate production and land also remained subjective to various haphazard implications. Therefore, a realization of the historical need, the Man-Made River Project embodied the solid spirit that had tackled challenges of the times such as “Water Disputes” and “Wars for food”. An effort ultimately regarded the last realistic serious and real effort to save life on earth. Consequently, greetings to this great project, as pure clean water should flow from its natural resources beneath the desert at the southern parts of Libya, which had been accumulating for thousands of years during the rainy epoch and settled at the rocky layers. These waters should be converted into a natural flow from South to North and would nourish the fertile agricultural lands. Great Man-Made River (GMMR) Project played a special role in the series of gigantic achievements achieved by the Arab Libyan People, embodied in an advanced civilization, to benefit from the immense underground water reserves latent in aquifers in the heart of the desert [75]. This was represented by the largest Water System of its kind to transfer huge amounts of water from the desert to the suitable soils in the coastal areas through huge buried pipelines,hence forming the largest man-made irrigation Conveyance System in the world known to human’s beings so far. And the largest civil engineering project at present times.

3.4.1. Groundwater Basins

The whole process is considered self-sufficient for its unique and reliable functions. It contained pure water which, accumulated during the rainy epoch for several decades. These underwater basins are the source of irrigation for agriculture and fertile land. It is also a source of drinking for the local area people [78].

3.4.2. Al Serir Basin

This basin extended from the Serir region to the Mediterranean coast. Its waters were latent at a layer 600 meters deep, and had contained 1000 km^3 of waters. Therefore, 84% of this water was of good quality ready for usage [78].

3.4.3. Murzuq Basin

The second main basin is situated at Fezzan region south west of Libya covering an areaof 450,000 Units and contained 4800 km^3 of waters latent in the rocky aquifer 800 meters thick [79]. It is known for its good water quality and salinity not more than 300 (ppm). Studies also revealed that an Al Kufra and Murzuq basin has collectively contained a volume of water equivalent to 220 years with the Nile River flow.

3.4.4. Al Hamada Basin

This basin is located in the northern Fezzan region and extended along the Jabel Al-Sawda up to the Mediterranean Sea. Studies confirmed that waters of the Serir and Hamada basins are of lower quality. Several pieces of research proved that the water quality of these two basins, Serir and Hamada had decreased as they get closer to the coast of the Mediterranean Sea [80].

3.4.5. Al Kufra Basin

This basin is located east south of Jamahiriya. It was the largest of the main under-ground basins, covering an area of 350,000 km^2 and contained 3,400 km^3 of waters latent in the water-bearing layers at a depth of 2000 meters. Therefore, 90% of this under-ground reserve capacity was still awaiting exploitation. Al Kufra basin is singled out for its excellent water quality with its total salinity not exceeding 250 ppm [80].

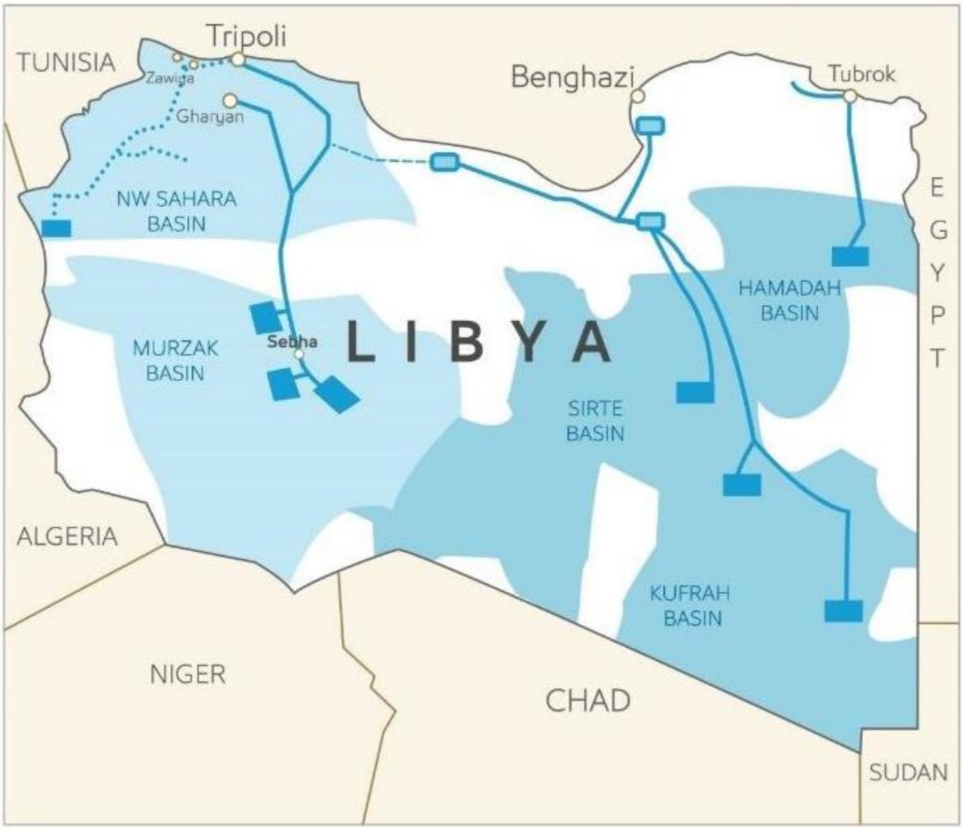

Figure 3.3. Groundwater distribution in Libya [81].

3.5. MANUFACTURE OF PIPES AND DIGGING TRENCHES

Moving these huge amounts of water latent at Al Kufra, Serir, Tazerbu and Fezzan basins from south to northern coast required a giant Conveyance System of large-scale pipelines. For this purpose, two of the most modern and largest factories in the world are established to produce pipes. One of which is located at Brega and the other in Serir, with a total production capacity of 220 pipes a day [82]. This ranked Libya today at the top of the list of Pre-Stressed Concrete Pipe Manufacturers in the world. Factors are taken into consideration on producing these pipes; nature of the region, type of earth which would accommodate pipelines, hence using material and substances that resisted corrosion and erosion and could with stand high-pressure fluctuation. Pre-fatigued concrete pipes were manufactured of iron, steel, cement, sand, gravel, grout,carbon and other reinforcing elements. Each pipe segment was 7.5 meters long, 4 meter diameters and weighs between 73 and 80 tons, buried in 7 meters wide, 7-meter-deep land trench. Tons of the soil produced in trench works were immediately transferred to pipe factories to be recycled in forming the pre-fatigued concrete paste for pipe fitting [82].

Figure 3.4. Connecting pipe segments Source [83].

Therefore, connecting pipe segments into one pipeline involved an accurate engineering process so that segments gradually overlap by means of rubber-bands in accordance to the accurate specifications. These laid pipes were extended from sourcesof water in the south to north of Libya for more than 4000 km. So the Great River of Pipes was ready and equipped to accommodate and transfer immense amounts of freshwater to cover all coastal areas in Libya, in particular to lands suitable for agriculture [83].

3.6. WATER TRANSPORTATION SYSTEMS

This great achievement is executed through several huge Conveyance Systemsto transfer water cross the great desert from south to north, to provide large amounts of freshwater for drinking and agriculture, at an estimated rate of 6.5 million cubic meters daily [84]. Through the following Water Systems:

3.6.1. Tazerbu Benghazi – Serir Sirte Water System

This Water System carried 2 million m^3 of freshwater per day through two main lines, first of which had carried water from Tazerbu water fields and the other from Al Serir water fields east-south of Libya. The two main lines are directed northward to the collection and balance reservoir in Ajdabia [84]. The capacity of which is 4 million m^3 of water and Conveyance System was bypassed in two branches from that place.

Therefore, one of them extended to the east to carry 1.18 million m³ of water to Omar Mukhtar reservoir with a capacity of 4.7 million m³. While the other branch headed westward carrying 820,000 m³ of water to settle in Ghurdabia Reservoir at Sirte capacity of each 6.8 million m³ of water. Consequently, 234 producing wells feed that conveyance system 126 of which at Serir region, and 108 wells at Tazerbu region. Well depth varied in both fields from 450 to 650 meters. This water trip from the well fields to the coast had taken about nine days at a speed of 0.95 m/sec [84].

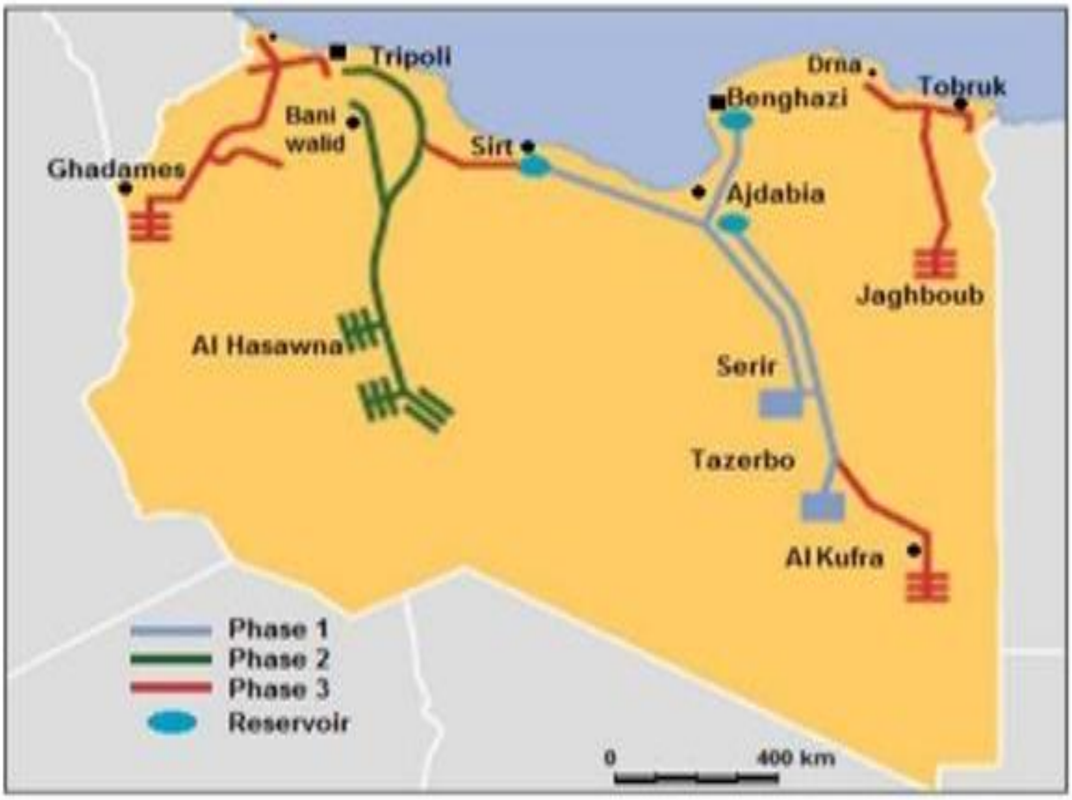

Figure 3.5. Water transportation system [84].

3.6.2. "Al-Hasawna Al-Jefara" Water System

This Water System aimed to transfer 2.5 million m³ of fresh water every day from the west-south of Libya, precisely from the Jabel Hasawna region situated above Murzuq natural basin to the western coast and the fertile lands in Jefara Plain. This water system extended to 1.676 km length fed by 484 producing wells, 168 of which were situated at North East Jabel Hasawna field and 316 wells at East of Jabel Hasawna. The ultimate well depth in both areas varied from 400 to 600 meters, 50 km to the North, Con-veyance System line splits into the following two branches [84]:

- **Central Branch**: This line headed northward across the Wadi Zamzam region and Sof El-Jean Bene Walid to the regulating reservoir in Tarhouna Region. This routing was then directed towards Jabel Nafusa through a tunnel of 288 meters long to Jefara Plain. From that place, Abu Zayan Reservoir feeds Jabel Gharbi region with water. This line carried 0.834 million m³ of water, per day [84].

- **Eastern Branch**: This branch headed eastern northward from a point that lies between Wadi Girza and Wadi Rashada at Esdada. This branch would be directed to the west along the coastal highway, passing close to Misurata, Zlieten, Al Khums until it reached its ultimate destination at Gharabulli. The balance reservoir is erected at 160 meters above sea water level. From this reservoir water is carried over to Tripoli and surrounding regions, and also to supply irrigation water to agriculture projects at Jefara Plain This bypass carried 1.7 million m³ of water daily [84]. It is worthwhile to note here that this Conveyance System was more difficult to execute for its extensions pass through rough lands with many hills and canyons and rocky surfaces.

3.6.3. Jaghbub- Tobruk Water System

This Conveyance System aimed to carry 120,000 m³ of fresh water per day from Jaghbub fields that contained 20 producing wells to Tubruk and local areas [85].

3.6.4. Ghadames – Zuara - Zawia Water System

This Conveyance System should carry a quarter of a million m³ of fresh water per day from Ghadames basin comprising 143 producing wells to Zuara, Zawia and close by cities [85].

3.7. DROUGHT INDICES OVERVIEW

The DrinC (Drought Indices Calculator) aimed at providing a user-friendly tool for the calculation of several drought indices. Key objective in its design is the widest possible applicability for several types of droughts (meteorological, hydrological, agricultural) and different locations. It is also considered that drought studies were particularly essential in arid and semi-arid regions, where data availability is usually limited. Therefore, the main criteria for the selection of indices are [86]:

- To have relatively low data requirements, allowing the application of the software in many regions.
- Their results to be clearly interpreted for direct and efficient operationaluse.

The process is based on these criteria, two recently developed and two more widely known indices are included in DrinC:

- The Reconnaissance Drought Index (RDI)
- TheStream Flow Drought Index (SDI)
- Standardized Precipitation Index (SPI)
- Precipitation Deciles (PD).

They could be easily understood; RDI, SPI and PD referred to the meteorological drought and used as the main determinant the precipitation (and additionally the potential evapotranspiration for RDI only). Further, RDI could also beused for the agricultural drought analysis, as it could adequately describe the water balance, and it is particularly useful when reference periods related to developmentstages of the crop were selected [3]. On the other hand, SDI appliedto hydrological drought and had used stream flow as the key determinant [86].

Apart from the originally proposed methods of calculation for each index, DrinC incorporated alternative methods that allowed the comparison of the results among the indices. Further, this has given a 3 key advantage to the user, since it had provided the flexibility to select among various options for adjusting the outputs to his particular needs. Following, there is a short presentation and the key characteristics of the drought indices calculated by DrinC [86].

3.7.1. Standardized Precipitation Index (SPI)

The Standard Precipitation Index (SPI) is developed by McKee et al. to determine the effects of reduction in precipitation on groundwater, reservoir storage, soil moisture, snow drifts and streams. It is obtained by dividing the difference of precipitation from the mean, which is converted to normal distribution within the specified time period, by the standard deviation. In fact, SPI provides a standardized conversion of the observed precipitation probability and could be calculated for desired time periods such as 1, 3, 6, 9, 12, 24 and 48 months. The formula and classification of the method is given below [87]:

$$SPI = (X_i - X_i) / \sigma \qquad (3.1)$$

Where:

- SPI: Standard Precipitation Index
- Xi: amount of precipitation
- Xi: average of precipitation
- σ: standard deviation

Table 3.2. Index values and classification of SPI method.

SPI Index values	Drought Category
2.0 and above	Extremely wet
1.50 to 1.99	Very wet
1.00 to 1.49	Moderately wet
0 to 0,99	Mildly wet
-0.99 to 0	Mildly dry
-1.00 to -1.50	Moderately dry
-1.50 to -1.99	Severely dry
-2.0 and below	Extremely dry

In a drought assessment made by taking SPI values into consideration, the time period in which the index is constantly negative, defined as the "dry period". The first month in which the index is fallen below zero is considered the beginning of the drought, while the month in which the index raised to a positive value is considered the end of the drought [88].

3.7.2. Reconnaissance Drought Index (RDI)

The Reconnaissance Drought Index (RDI) is developed to approach the water deficit in a more accurate way, as a sort of balance between input and output in a water system [89,90]. It is based on both cumulative precipitation (P) and potential evapotranspiration (PET), which is one measured (P) and later calculated (PET) determinant. The initial value (α k) of RDI was calculated for the year in a time basis of k (months) as follows:

$$\alpha_k^{(i)} = \frac{\sum_{j=1}^{k} P_{ij}}{\sum_{j=1}^{k} PET_{ij}}, \mathrm{i} = 1(1)\mathrm{N} \text{ and } \mathrm{j} = 1(1)\mathrm{k} \quad (3.2)$$

Where:

- P_{ij} and PET_{ij} are the precipitation and potential evapotranspiration of the j-th month of the i-th year
- N is the total number of years of the available data
- The values of α_k follow satisfactorily both the lognormal and the gamma distributions in a wide range of locations and different time scales, in which they were tested.

By assuming that the lognormal distribution was applied, the following equation could be used for the calculation of RDI_{st} [91,92]:

$$RDI_{st}^{(i)} = \frac{Y^{(i)} - \overline{Y}}{\hat{\sigma}_y} \quad (3.3)$$

Where:

- $y^{(i)}$ is the $\ln(a_k)^{(i)}$
- y is its arithmetic mean
- σy is the standard deviation of y

From an extended research on various data from several locations and different time scales (3, 6, 9 and 12 months) it is concluded that the α_k values follow satisfactorily both the lognormal and the gamma distributions in almost all locations and time scales, but in most of the cases the gamma distribution is more successful. Therefore, the calculation of the RDI_{st} could be performed better by fitting the gamma probability density function (pdf) to the given frequency distribution of the αk, following the procedure described below [91,92]. This approach also solved the problem of calculating the RDIst for small time steps, such as monthly, which might include zero-precipitation values (α_k = 0), for which Eq. (2) could not be applied. The gamma distribution was defined by its frequency or probability density function:

$$g(x) = \frac{1}{\beta^{y}\, I\,(\gamma)}\; x^{y-1}\, e^{-x/\beta}\;\;,\quad for\; x > 0 \tag{3.4}$$

Where:

- γ and β are the shape and scale parameters respectively,
- x is the precipitationamount
- Γ(γ) is the gamma function.

Parameters γ and β of the gamma pdf areestimated for each station and for each time scale of interest (1, 3, 6, 9, 12 months, etc.). Maximum likelihood estimations of γ and β are and n is the number of observations [91,92].

$$Y\frac{1}{4A}\left(1+\sqrt{1+\frac{4A}{3}}\right), \beta\frac{\bar{x}}{y}\;, Where\; A = In\,(\bar{x}) - \frac{\sum In\,(x)}{n} \tag{3.5}$$

The resulting parameters are then used to find the cumulative probability of α_k for a given year for the location in question. Since the gamma function is undefined for x= 0 and a precipitation distribution might contain zeros, the cumulative probability became:

$$H(x) = q + (1 - q)G(x) \tag{3.6}$$

Where [93]:

- q is the probability of zero precipitation
- G(x) is the cumulative probability of the incomplete gamma function
- If m is the number of zeros in a αk time series, then q could be estimated by m/n. The cumulative probability H(x), is then transformed to the standard normal random variable z with mean zero and variance of one which is the value of the RDI_{st}.

Positive values of RDIst indicated wet periods, while negative values indicated dry periods compared with the normal conditions of the area. Drought severity could be categorized in mild, moderate, severe and extreme classes, with corresponding boundary values of RDIst as shown in the given Table 3.3.

Table 3.3. Corresponding boundary values of RDIst

Mild	**Moderate**	**Severe**	**Extreme Classes**
-0.5 to -1.0	- 1.0 to -1.5	-1.5 to -2.0	< -2.0

3.7.3. The Drought Indices Calculator (DrinC) Software

There has been a lot of work put into developing DrinC (Drought Indices Calculator), a piece of software designed to make it easy to calculate drought indices. Reconnaissance Drought Index (RDI) and Streamflow Drought Index (SDI) may both be calculated using DrinC, as well as the Standardized Precipitation Index (SPI) and the Precipitation Deciles (PD) indices. RDI may also be calculated using a module that uses temperature-based techniques to estimate potential evapotranspiration (PET). Drought monitoring, the evaluation of drought's geographical distribution, the analysis of climate and drought scenarios, and so on, may all benefit from the software DrinC is gaining popularity as a research and operational tool for drought analysis in arid and semi-arid countries, where it has been tested extensively [94].

PART 4

RESEARCH FINDINGS AND DISCUSSION

4.1. RESEARCH ANALYSIS

The findings and discussion of the data that collected from 5 monitoring stations (Zuara Station (62007), Tripoli Airport Station (62010) Nalut Station (62002), Misurata Station (62016), Sirt Station (62019)) from the state meteorological station and Libya in the region of The Great Man-Made River are given below;

Within the scope of this research, the SPI and RDI values for 1-, 3-, 6- and 12-months arecalculated and evaluated using the method of the Precipitation Drought Index and Reconnaissance Drought Index. The process used the values of the monthly total precipitation and monthly mean temperature of 5 monitoring stations from the state meteorological station and Libya in the region of The Great Man-Made River.

4.1.1. Zuara Station (62007) Meteorological Drought Analysis

Zuara Station, computed using continuously measured monthly total precipitation data between 1980-2009. SPI values were examined during periods 1, 3, 6 and 12 months. The SPI values are calculated for the Zuara station. The rate of dryness and humidity of monthly is shown in the Figure 4.1. The figure hereby shows that the monthly dryness ranged between 48% and 79% according to SPI values. The highest dry period September, and the lowest wet period was 3% in July, and the dry and humid periods are equal in November and December, with no drought in July. The period of drought and moisture for each of 3-, 6-, and 12- months for the SPI values are shown in Figure 4.2. The Driest periods with the highest SPI -3 values are SPI3-3 in April of 54% and the lowest dry period is SPI3-4 July with 46%.

Dryness and moisture are equal in SPI6-1 October at 50% SPI6-2 in April the droughts are 46% and 54% respectively. SPI-12 calculated according to 12-month values Dryness is 54% and moisture is 46%.

According to Figure 4.3, when the values of one-month SPI obtained from the monthly rainfall data, for a 29-year period in the Zuara monitoring station are examined. The presence of abnormally dry was determined in July for a period of 15 years, while the highest drier period was in December 2000-2001; the highest moist period was July 1985-1986. Figure 4.4 shows the distributions time of SPI values for 3-, 6- and 12-months examination of SPI values for 3 months, SPI-3 October year 1981-1982 severely dry period, year 1984-1985 exceptional moist period, SPI-3 January year 1980- 1981 exceptional dry, year 1989-1990 very moist, SPI-3 April 88-1989, 1998-1999 identified as severely dry period and year 93-1994 exceptional moist, SPI-3 July 1980-1981 and 93-1994 identified as a moderate dry and the year 87-1988 was identified as exceptional moist. When the SPI values are checked for six months, SPI-6 October year 2000-2001 and SPI-6 April 98-1999 are examined to be extremely dry. According to SPI-12 values, the year 2000-2001 was defined as exceptional dry and the year 84-1985 is exceptional moist.

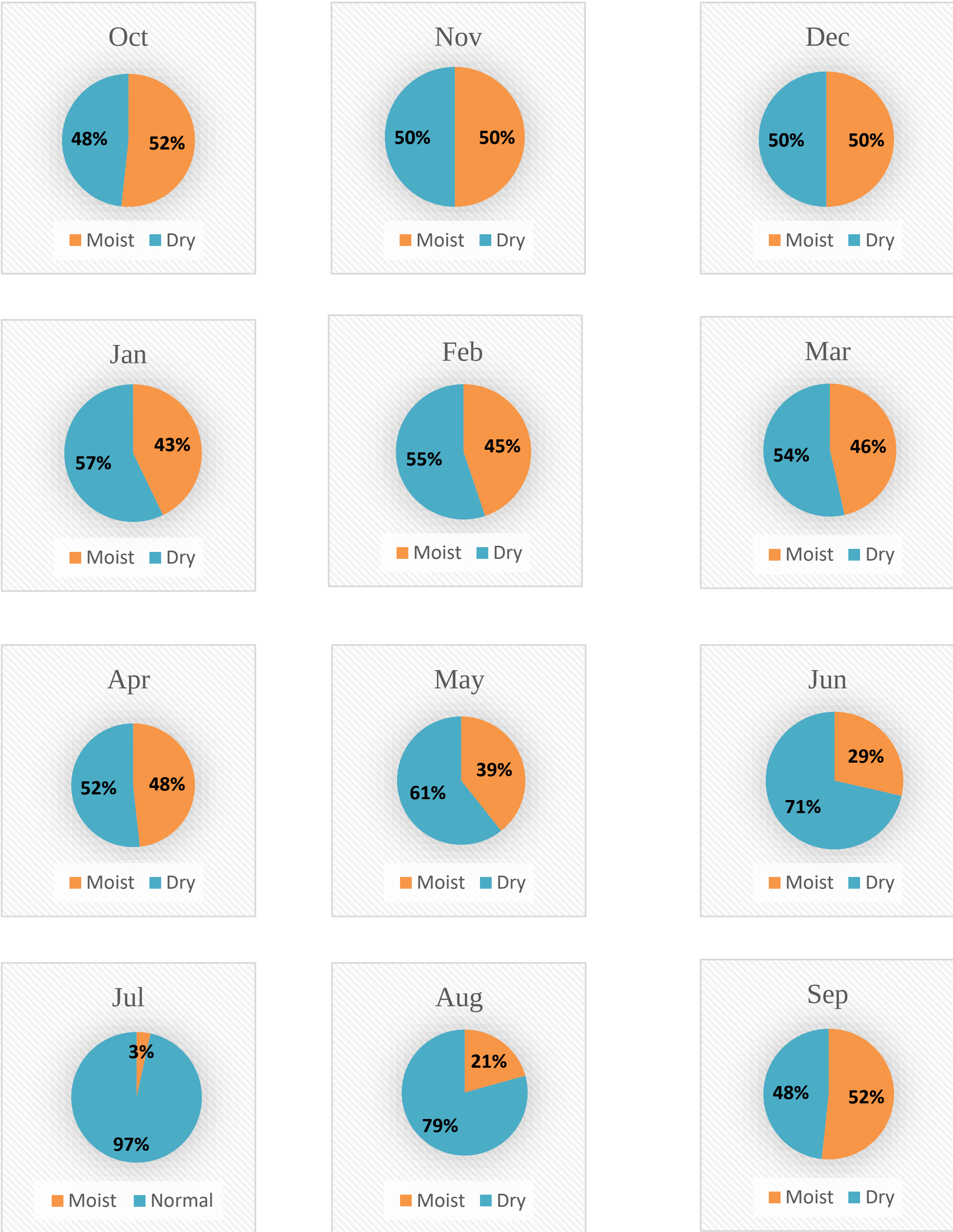

Figure 4.1. Dry - moist period distributions according to the monthly SPI values for the Zuara station (No. 62007).

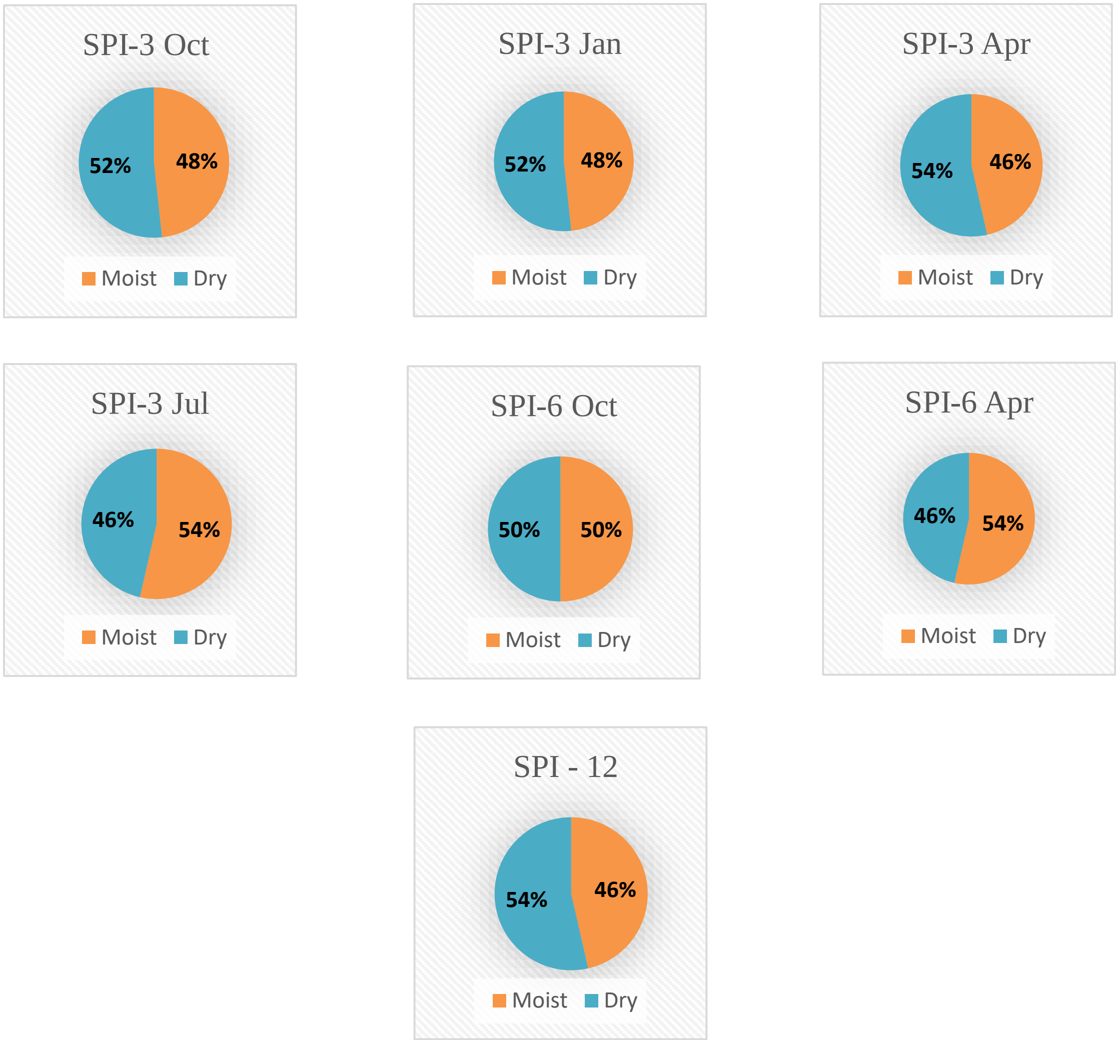

Figure 4.2. Dry - moist period distributions according to the 3,6,12 month SPI values for the Zuara station (No. 62007).

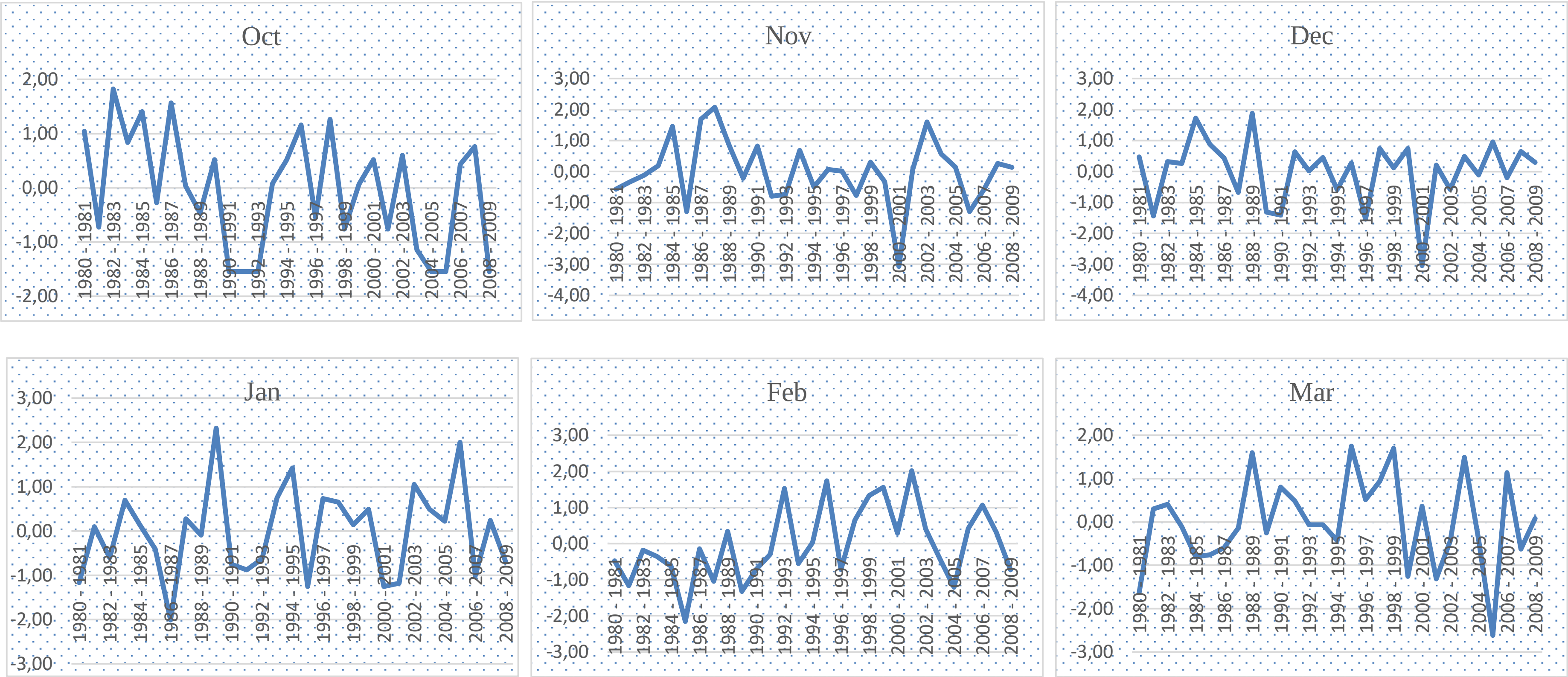

Figure 4.3. Temporal distribution of monthly SPI values of the Zuara station (No.62007).

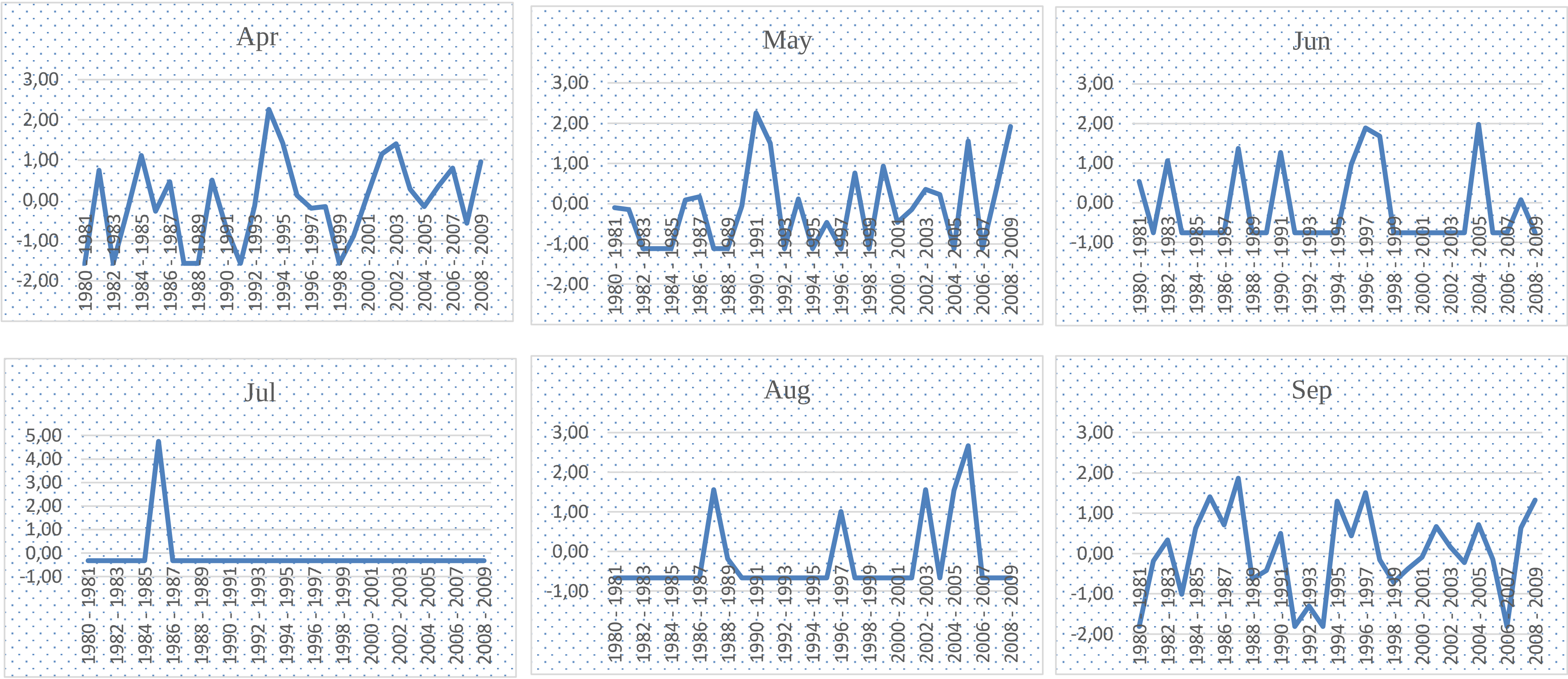

Figure 4.4. (Continued).

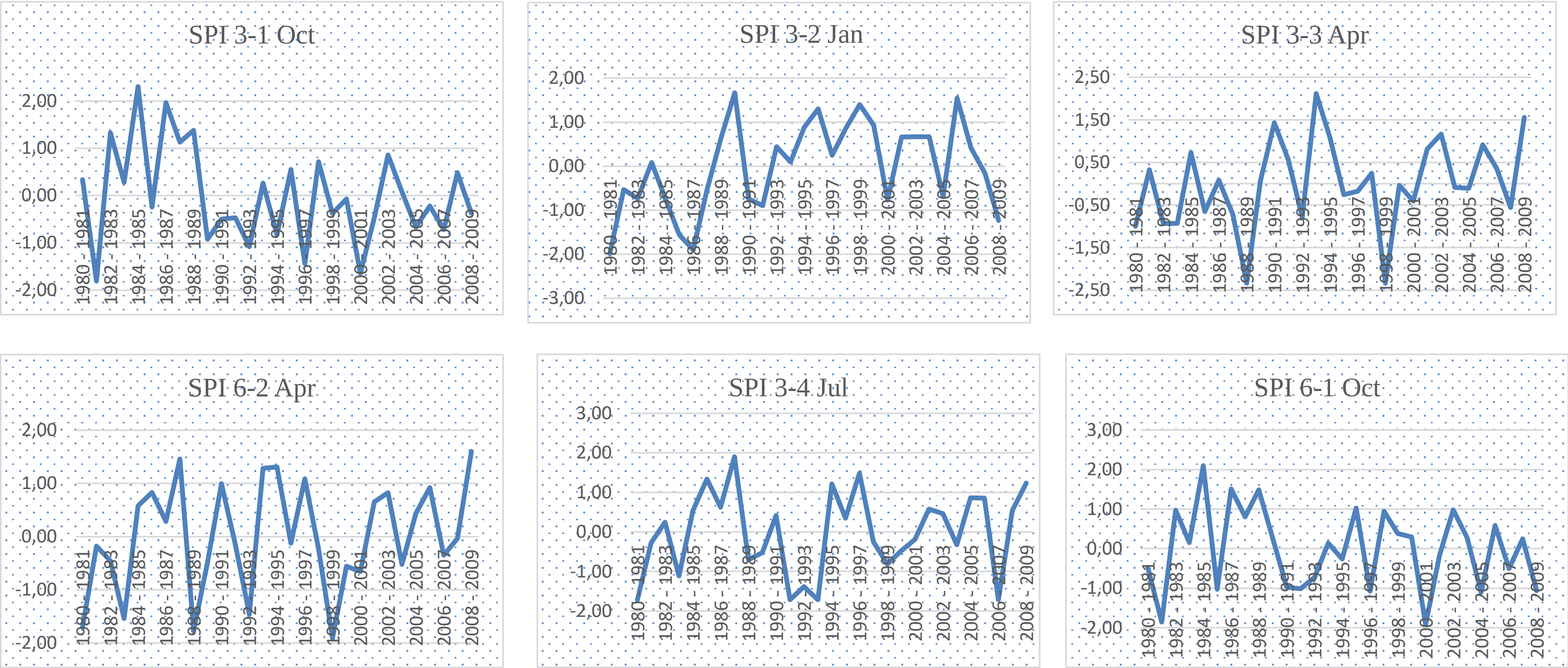

Figure 4.5. Temporal distribution of 3, 6, and 12 month SPI values of the Zuara station (No.62007).

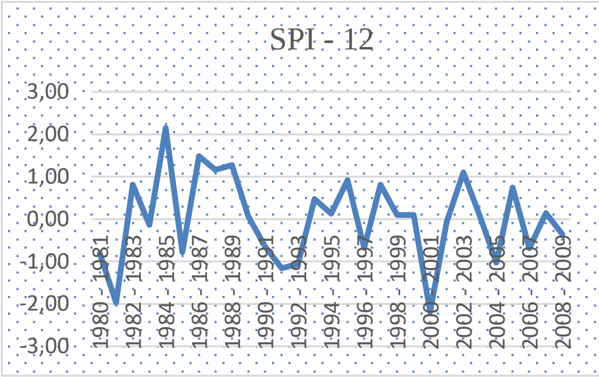

Figure 4.6. Continued.

4.1.2. Tripoli Airport Station (62010) Meteorological Drought Analysis

Tripoli Airport Station computed using continuously measured monthly total precipitation data between the year 1980-2009, SPI values are examined during periods 1, 3, 6 and 12 months. The SPI values are calculated for the Tripoli Airport control station. Figure 4.5 and Figure 4.6, shown the rates dryness and humidity of monthly, 3- , 6-, and 12-months respectively. The Figure 4.5, show that the monthly dryness ranged between 46% and 86% according to SPI values. The highest dry period is 86% in July and 76% in June, with the lowest dry 46% period in December and November. When analyzed, the wet periods were the period with a high moist of 54% in November, December, February, and March, and the lowset wet period was 10% in August. The periods of drought and moisture for each of 3-, 6-, and 12- months for the SPI values are shown in Figure 4.6. The most. Dry periods with the highest SPI - 3 values are SPI3-3 in April of 61% and the lowest dry period is SPI3-4 July with 46%. For the periods SPI6-1 in October and SPI6-2 in April, the droughts were 54% and 55%, respectively. SPI-12 calculated according to 12-month values dryness is 46% and moisture is 54%. According to Figure 4.7, when the one-month SPI values obtained from the monthly total rainfall data for a 29-year period for the Tripoli Airport monitoring station are examined, the presence of abnormally dry was determined in month July for a period of 24 years, while the highest drier period was in November 2000-2001, the highest moist period was August 2004-2005. Figure 4.8, gives the time distributions of SPI values for 3-, 6- and 12-months, Examination of SPI Examination of SPI values for 3 months SPI-3 October year 2000-2001 extremely dry period, the year 1980-1981 exceptional moist period, SPI-3 January year 2008-

2009 extremely dry, the year 1981-1982 exceptional moist, SPI-3 April 1998-1999 extremely dry period and the year 1993-1994 exceptional moist, SPI-3 July severely dry and the year 1996-1997 were identified as exceptional moist. When the SPI values are checked for 6 months, SPI-6 October year 2000-2001 is extremely dry and SPI-6 April 1998-1999 is determined to be exceptionally dry. According to SPI-12 values, the year 2000-2001 was defined as exceptional dry and the year 1980-1981 exceptional moist.

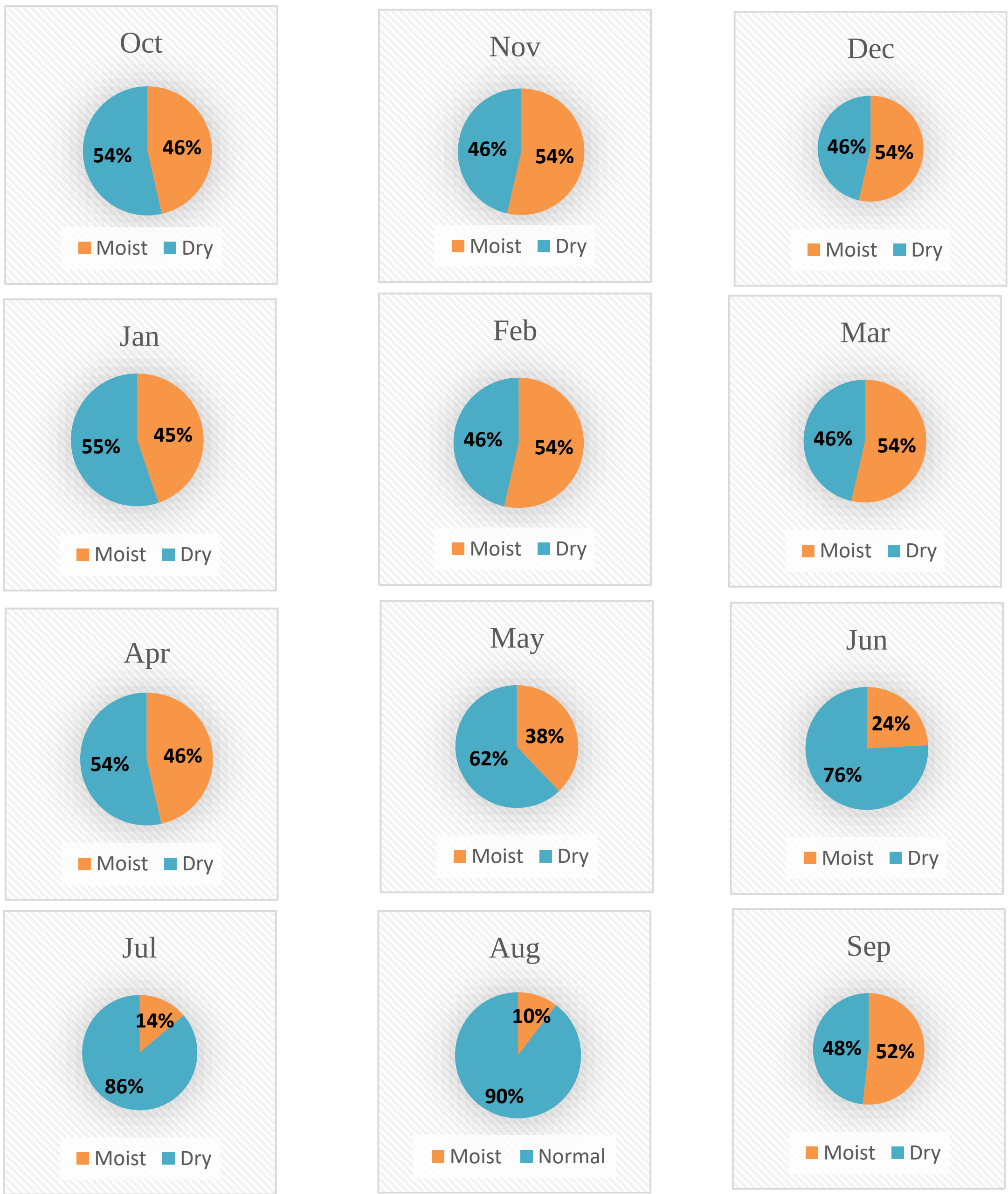

Figure 4.7. Dry - moist period distributions according to the monthly SPI values for the Tripoli Airport station (No. 62010).

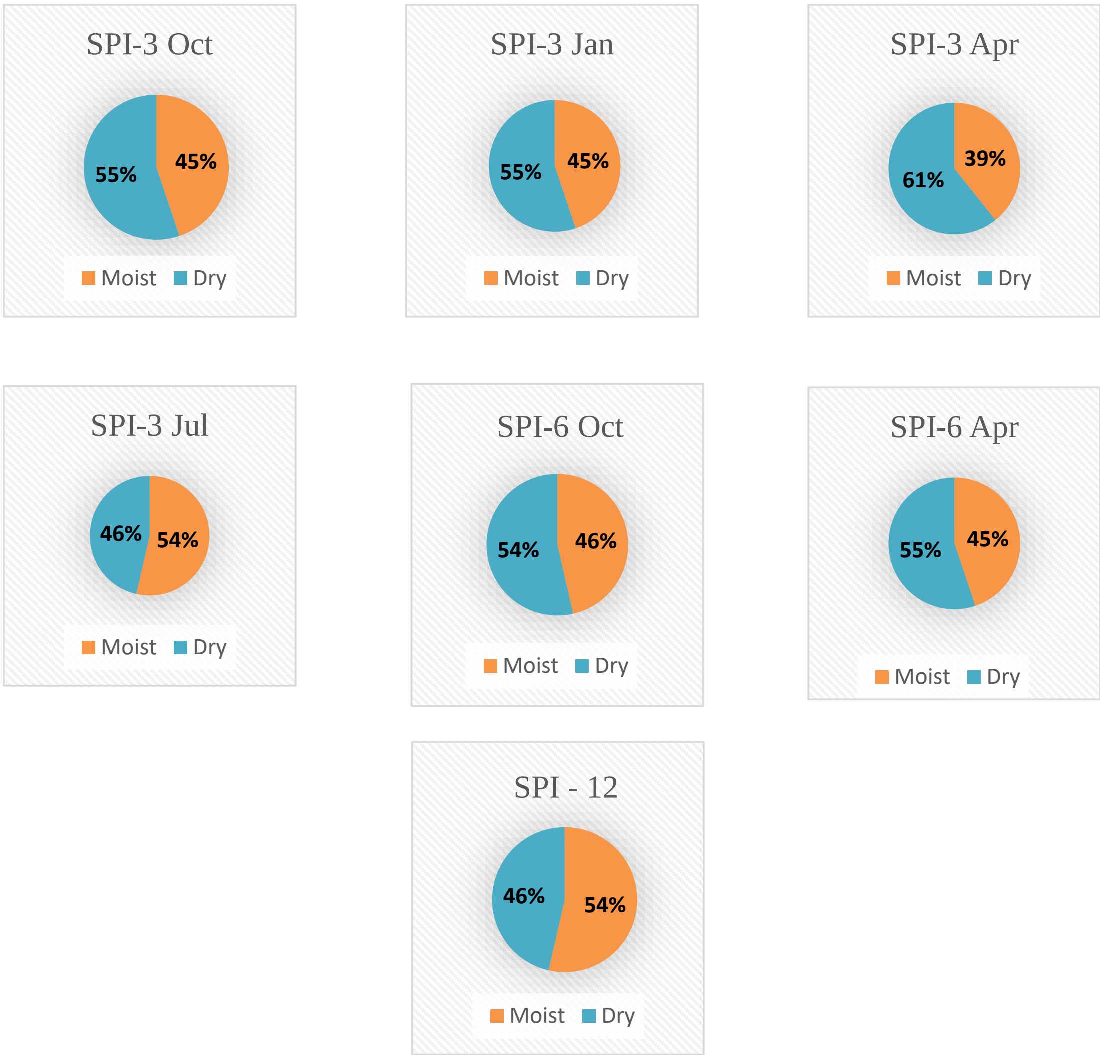

Figure 4.8. Dry - moist period distributions according to the 3,6,12 month SPI values for the Tripoli Airport station (No. 62010).

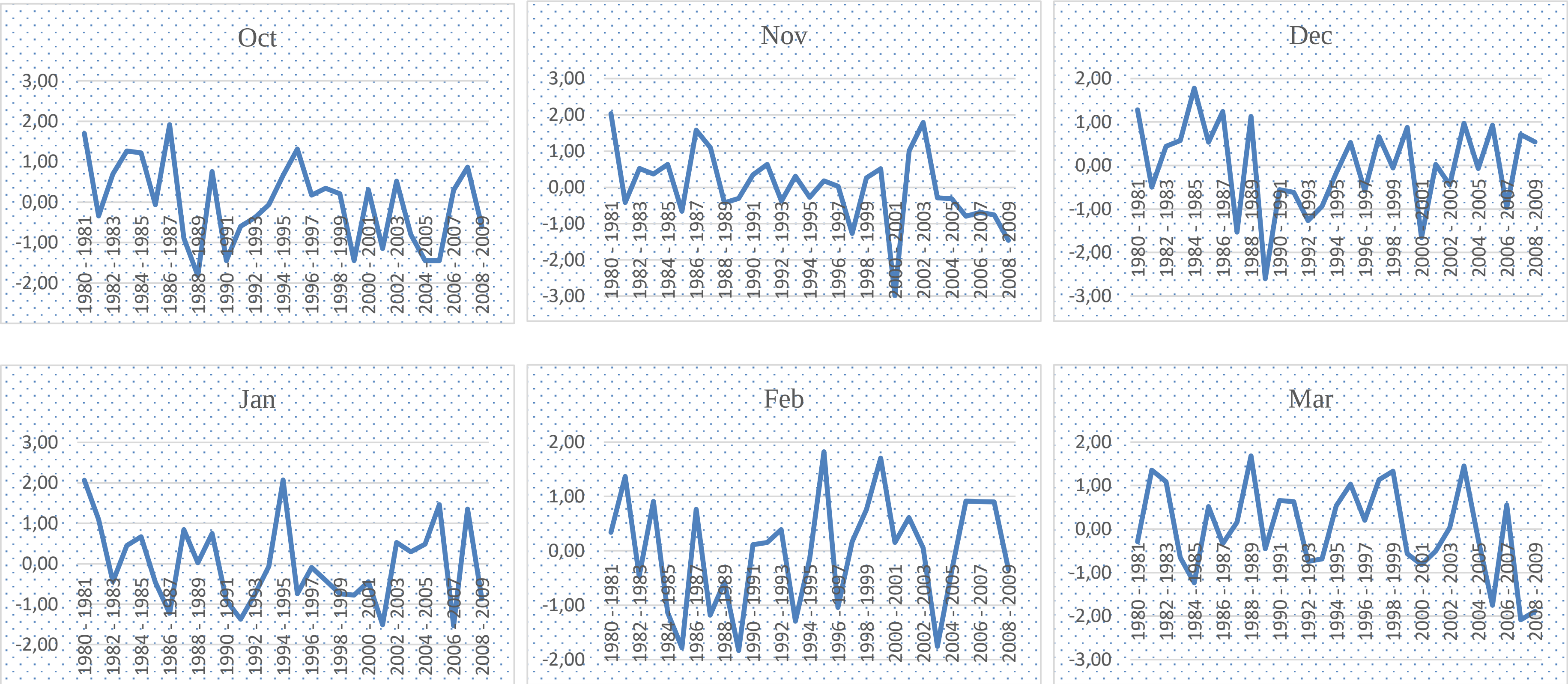

Figure 4.9. Temporal distribution of monthly SPI values of the Tripoli Airport station (No.62010).

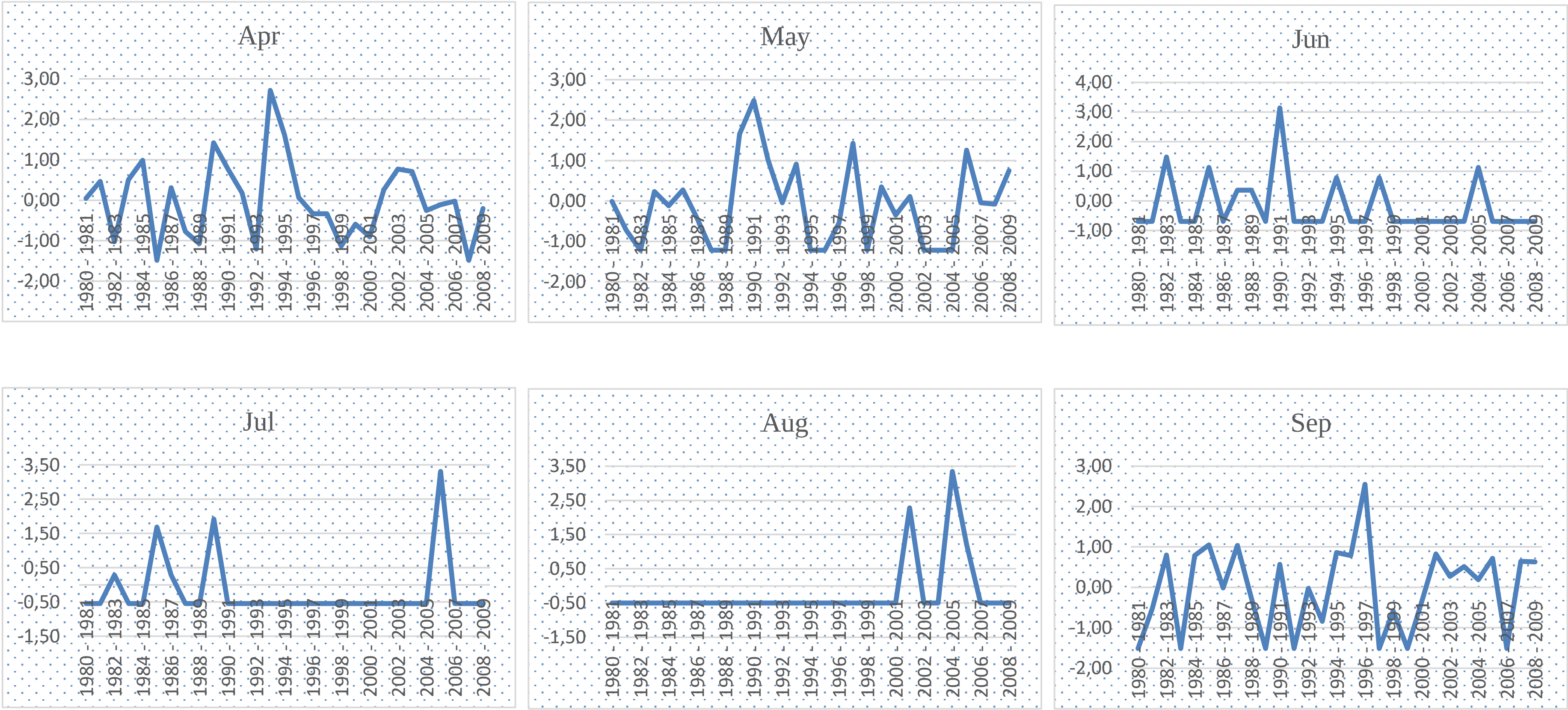

Figure 4.10. Continued.

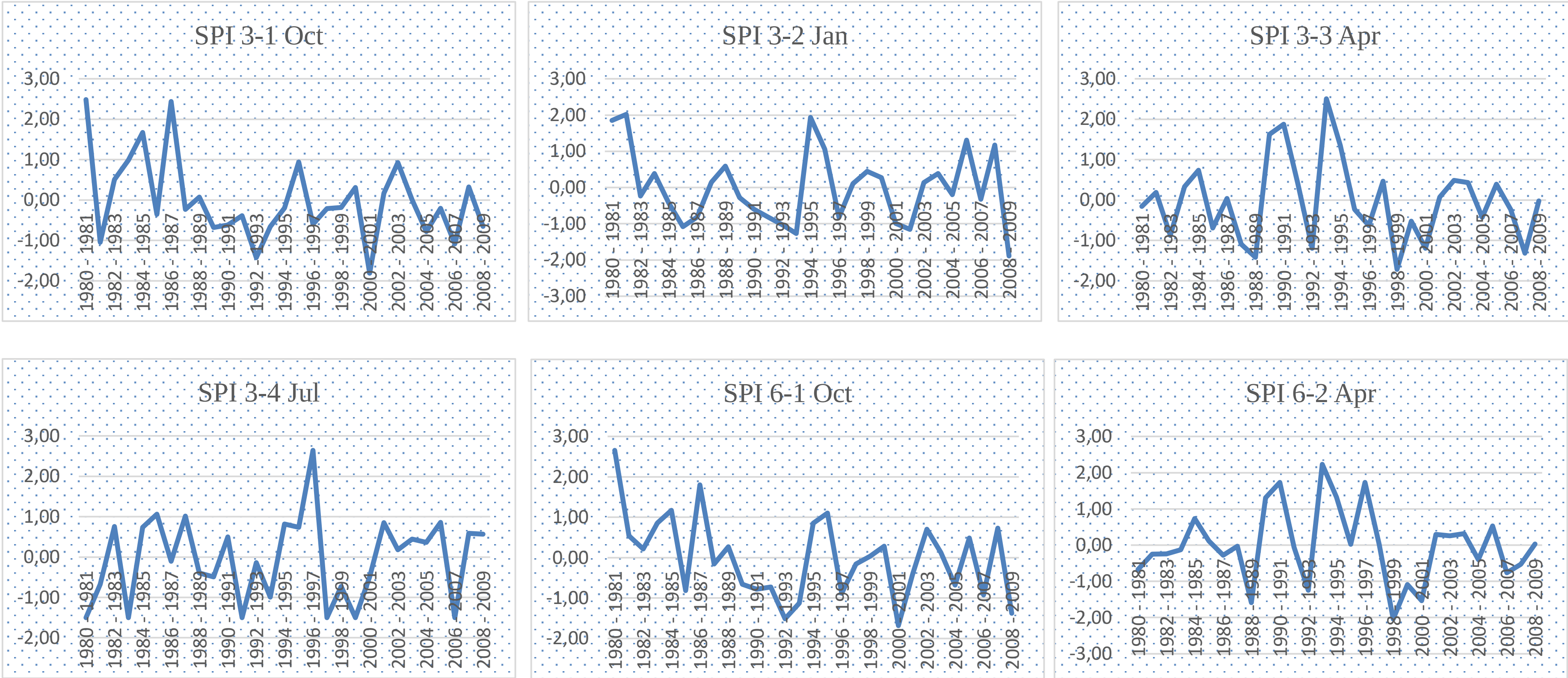

Figure 4.11. Temporal distribution of 3, 6, and 12 month SPI values of the Tripoli station (No.62010).

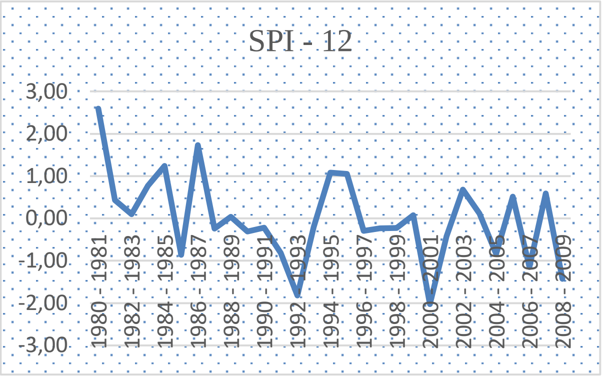

Figure 4.12. (Continued).

4.1.3. Nalut Station (62002) Meteorological Drought Analysis

Nalut Station computed using continuously measured monthly total precipitation data between the periods 1980-2009, SPI values are examined during periods 1-,3-,6-, and 12 months. The SPI values were calculated for the Nalut control station. Figure 4.9 and Figure 4.10 shows the rates of monthly dryness and humidity, 3- , 6-, and 12-months. In Figure 4.9, monthly dryness ranged between 69% and 86% according to SPI values. The highest dry period is 86% in August and 69% in June, with the lowest dry 45% period in March. The wet periods when analyzed were the period withhigh moist of 55% in March, and the lowest wet period was 7% in July. The period of drought and moisture for each of 3-, 6-, and 12- months for the SPI values are shown in Figure 4.10. The driest periods with the highest SPI -3 values are SPI3-2 in January of 55% and the lowest dry period is SPI3-1 October with 48%. For the periods SPI6-1 in October and SPI6-2 in April, the droughts were 52% and 55%, respectively. SPI-12 calculated according to 12-month values dryness is 52% and moisture is 48%. According to Figure 4.11, when the one-month SPI values obtained from the monthly total rainfall data for a 28-year period for the Nalut monitoring station were examined, the presence of moderate moist was determined in two months and moderate drought determined in 1month for a period of 25 years, while the highest drier period was in December 2000-2001, the highest moist period was July 1988-1989.

Figure 4.12 hereby shows the time distributions of SPI values for 3-, 6- and 12-months, Examination of SPI values for 3 months SPI-3 October year 1982-1983 exceptional dry period, the year 1995-1996 exceptional moist period, SPI-3 January year 2004-2005 exceptional dry, the year 1995-1996 exceptional moist, SPI-3 April 1998-1999 exceptional dry period and the year 1990-1991 exceptional moist, SPI-3 July year 1982-1983 severely dry and year 2007-2008 was identified as exceptional moist. When the SPI values are checked for 6 months, SPI-6 October year 1992-1993 is extremely dry and SPI-6 April 1983-1984 is determined to be exceptionally dry. According to SPI-12 values, the year 1992-1993 was defined as exceptional dry and the year 1995-1996 exceptional moist.

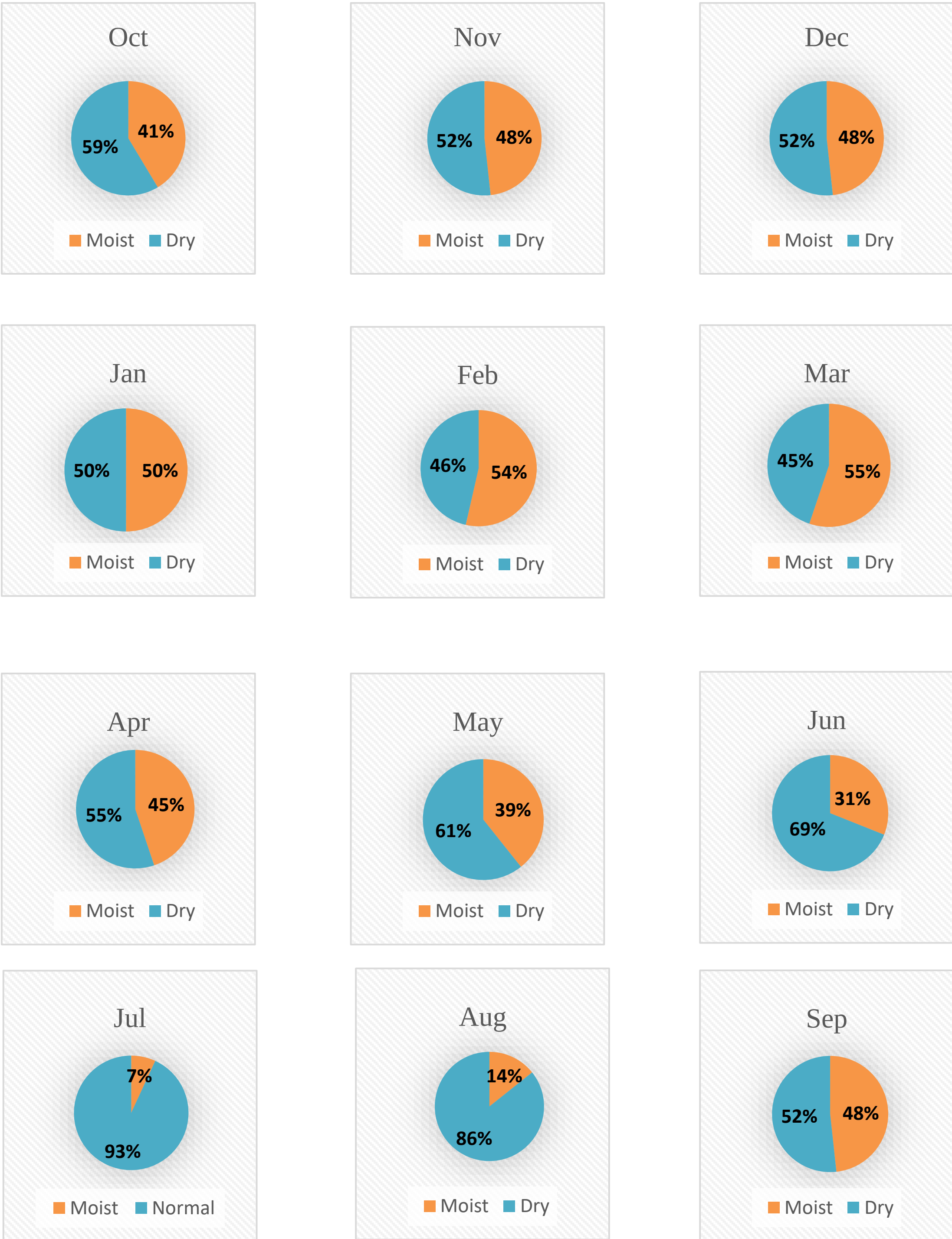

Figure 4.13. Dry - moist period distributions according to the monthly SPI values for the Nalut station (No. 62002).

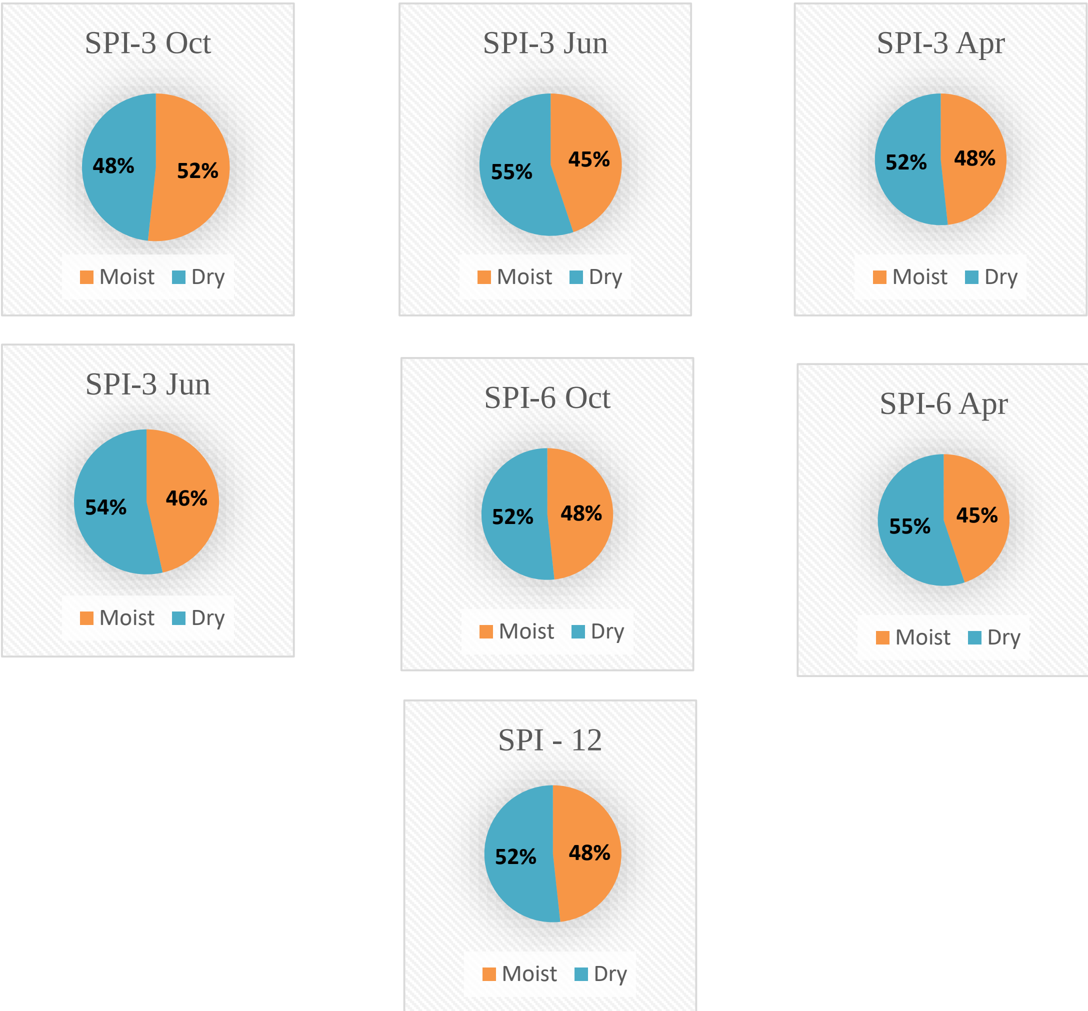

Figure 4.14. Dry - moist period distributions according to the 3,6,12 month SPI values for the Nalut station (No. 62002).

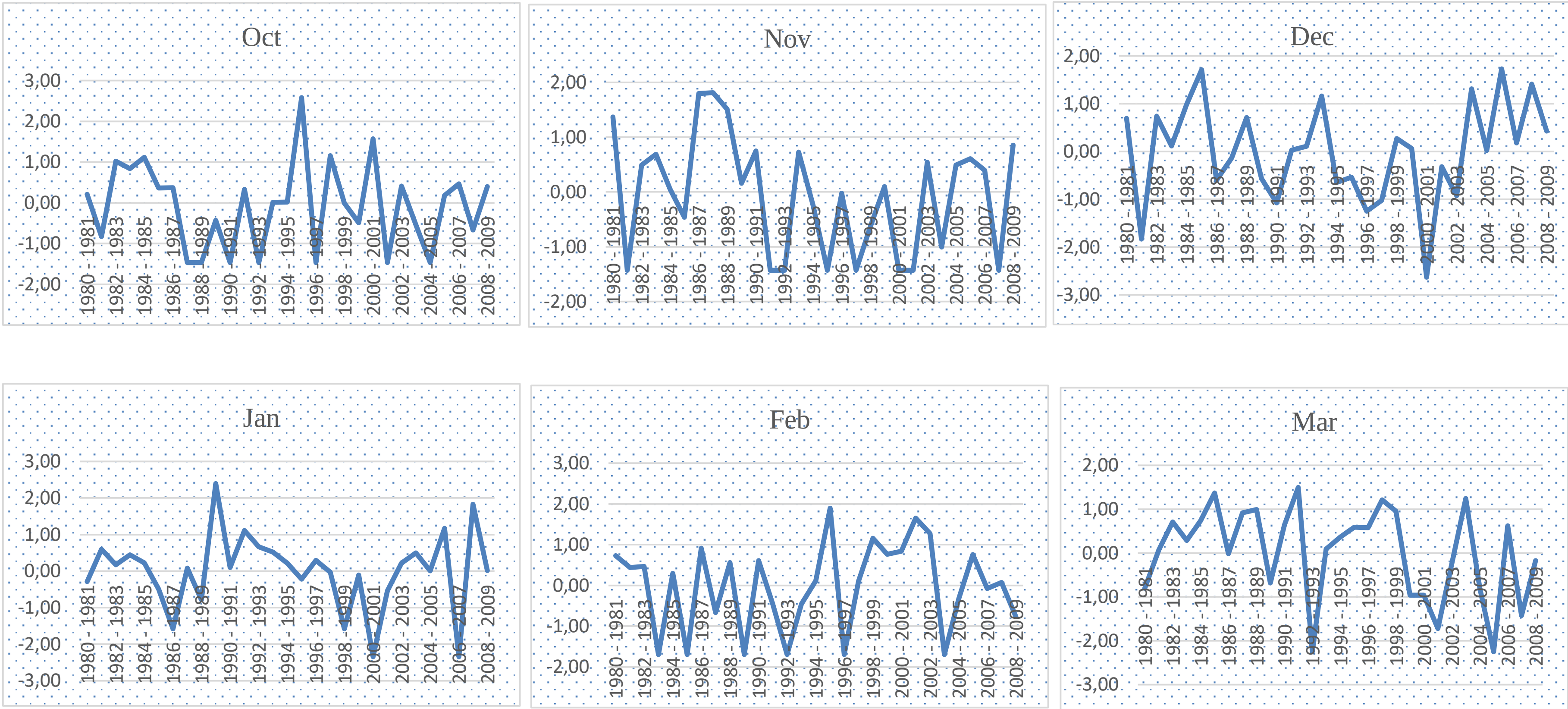

Figure 4.15. Temporal distribution of monthly SPI values of the Nalut station (No.62002).

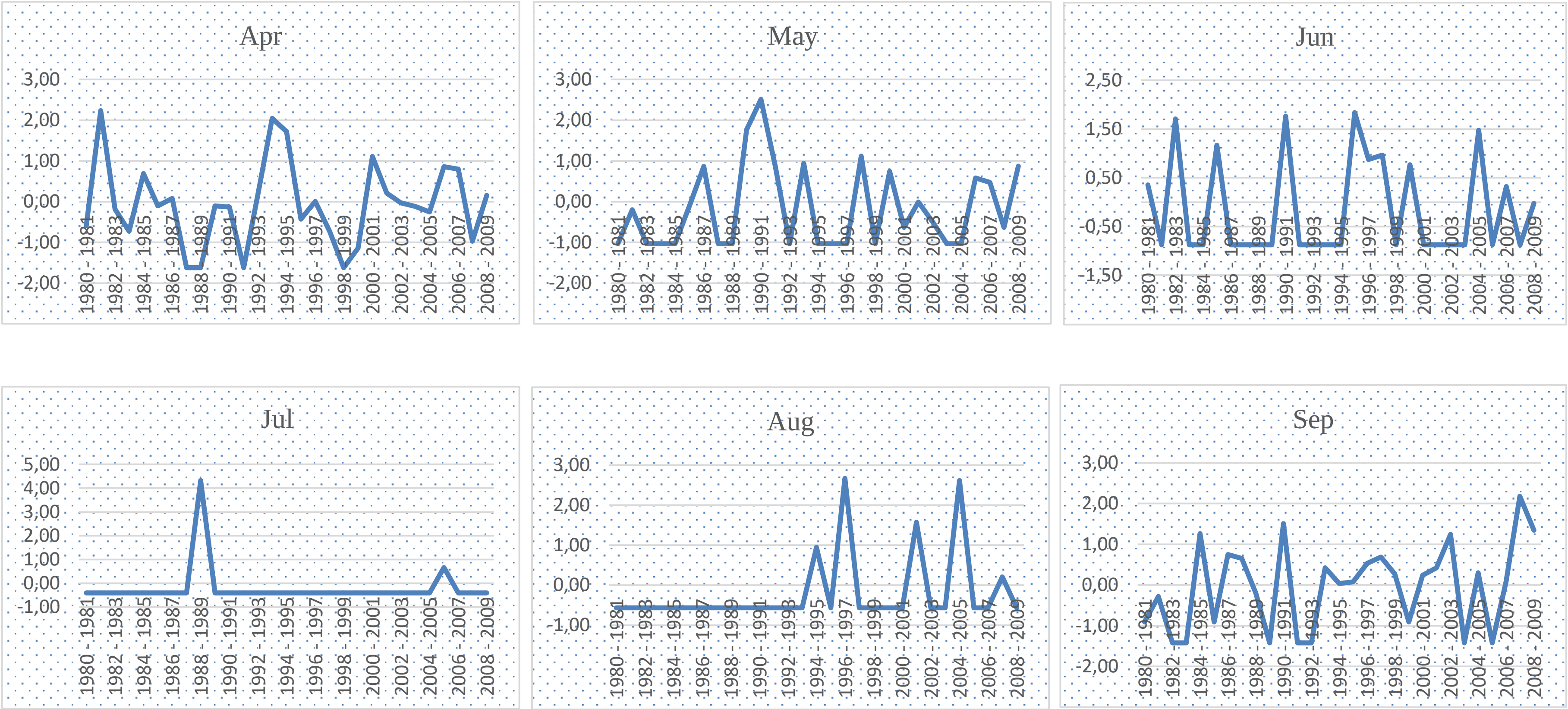

Figure 4.16. (Continued).

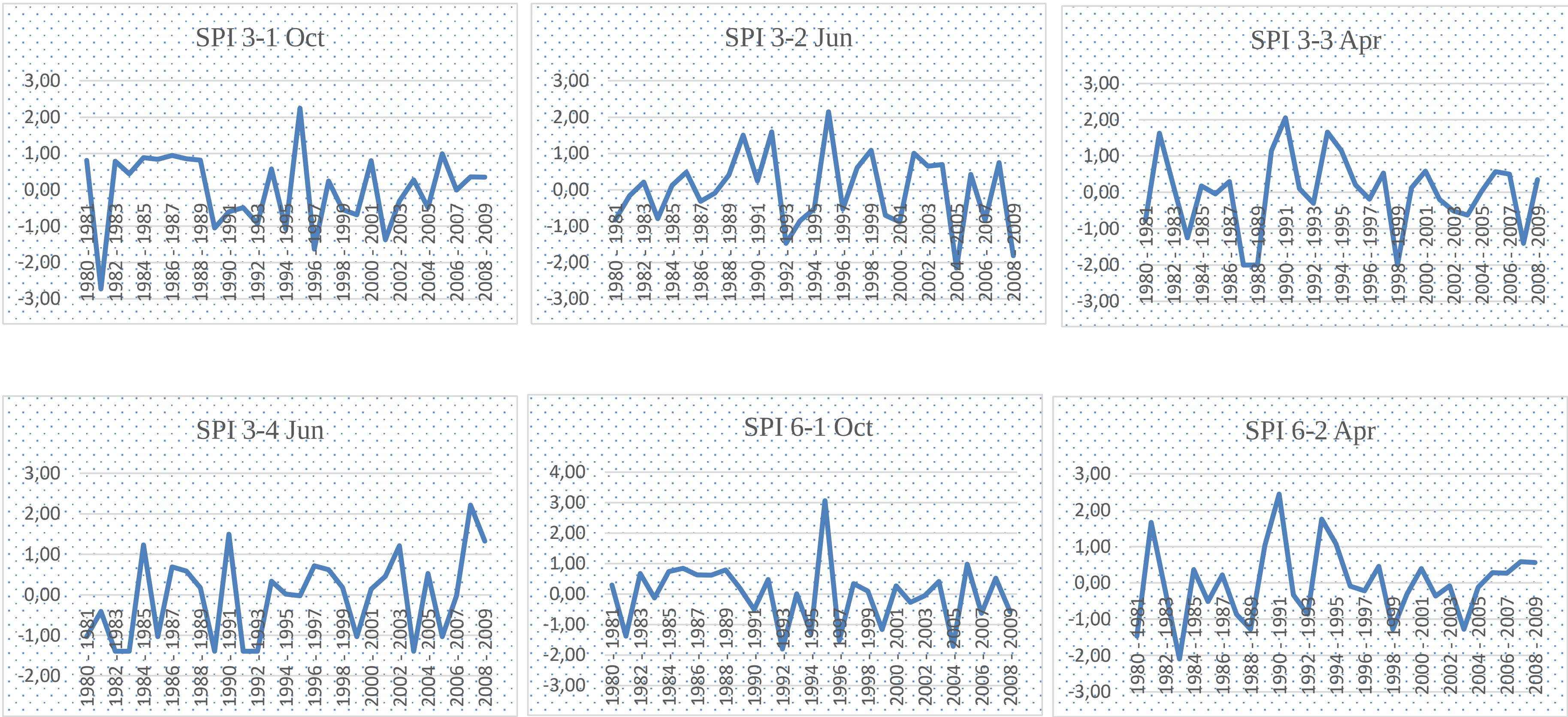

Figure 4.17. Temporal distribution of 3-, 6-, and 12 month SPI values of the Nalut station (No.62002).

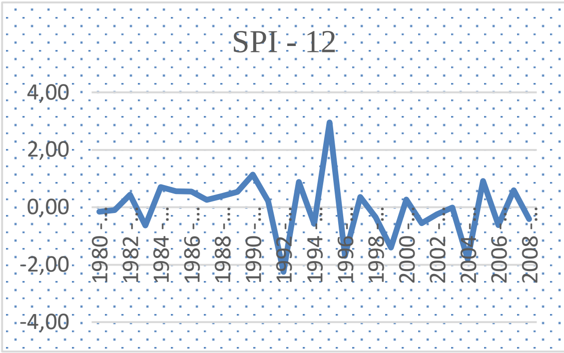

Figure 4.18. (Continued).

4.1.4. Misurata Station (62016) Meteorological Drought Analysis

Misurata Station computed using continuously measured monthly total precipitation data between 1980-2009, SPI values are examined during periods 1-, 3-, 6-, and 12 months. The SPI values were calculated for the Misurata control station. Fig-4.13, Fig-4.14 shown the rates of monthly dryness and humidity, 3-, 6- and 12 months. In Figure-4.13, monthly dryness ranged between 39% and 79%according to SPI values. The highest dry period is 79% in August and 71% in June, with the lowest 39% dry period in April. The wet periods when analyzed were the period with a high moist of 61% in April, and the lowest wet period was 7% in July.

The periods of drought and moisture for each of 3-, 6-, and 12 months for the SPI value are shown in Figure 4.14. The most, dry periods with the highest SPI -3 values are SPI3-2 in January of 54%, and the lowest dry period is SPI3-1 October with 46%. For the periods SPI6-1 in October and SPI6-2 in April, the droughts were 46% and 52%, respectively.SPI-12 calculated according to 12-month values dryness is 52% and moisture is 48%. According to Figure 4.15, when the one-month SPI values obtained from the monthly total rainfall data for a 29 year period for the Misurata monitoring station are examined, the presence of Abnormally dry was determined in month August for 19 years, while the highest drier period was in March 1999-2000, the highest moist period was July 1995-1996.

Figure 4.16 gives the time distributions of SPI values for 3-, 6-, and 12 months. Examination of SPI values for 3 months SPI-3 October year 1992-1993 extremely dry period, the year 1986- 1987 extremely moist period, SPI-3 January year 1984-1985 severely dry, the year 1994-1995 exceptional moist, SPI-3 April year 1998-1999 extremely dry period and the year 1990-1991 exceptional moist, SPI-3 July year 1980-1981 severely dry and the year 1987-1988 was identified as exceptional moist. When the SPI values are checked for 6 months, SPI-6 October year 1993-1994 is extremely dry, and SPI-6 April 1982-1983 is determined to be extremely dry. According to SPI-12 values, the year 2001 was defined as extremely dry and the year 1980-1981 exceptional moist.

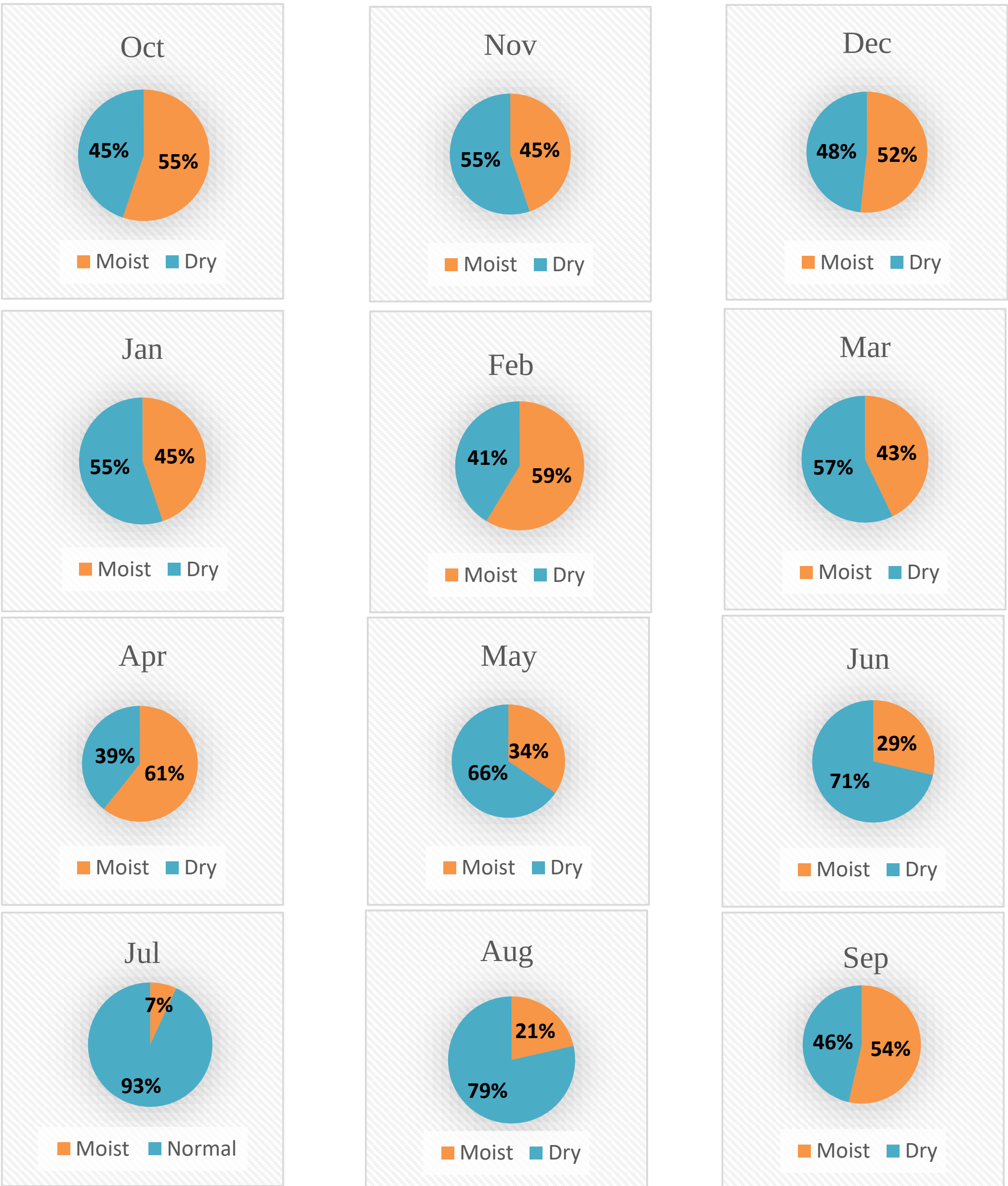

Figure 4.19. Dry - moist period distributions according to the monthly SPI values for the Misurata station (No. 62016).

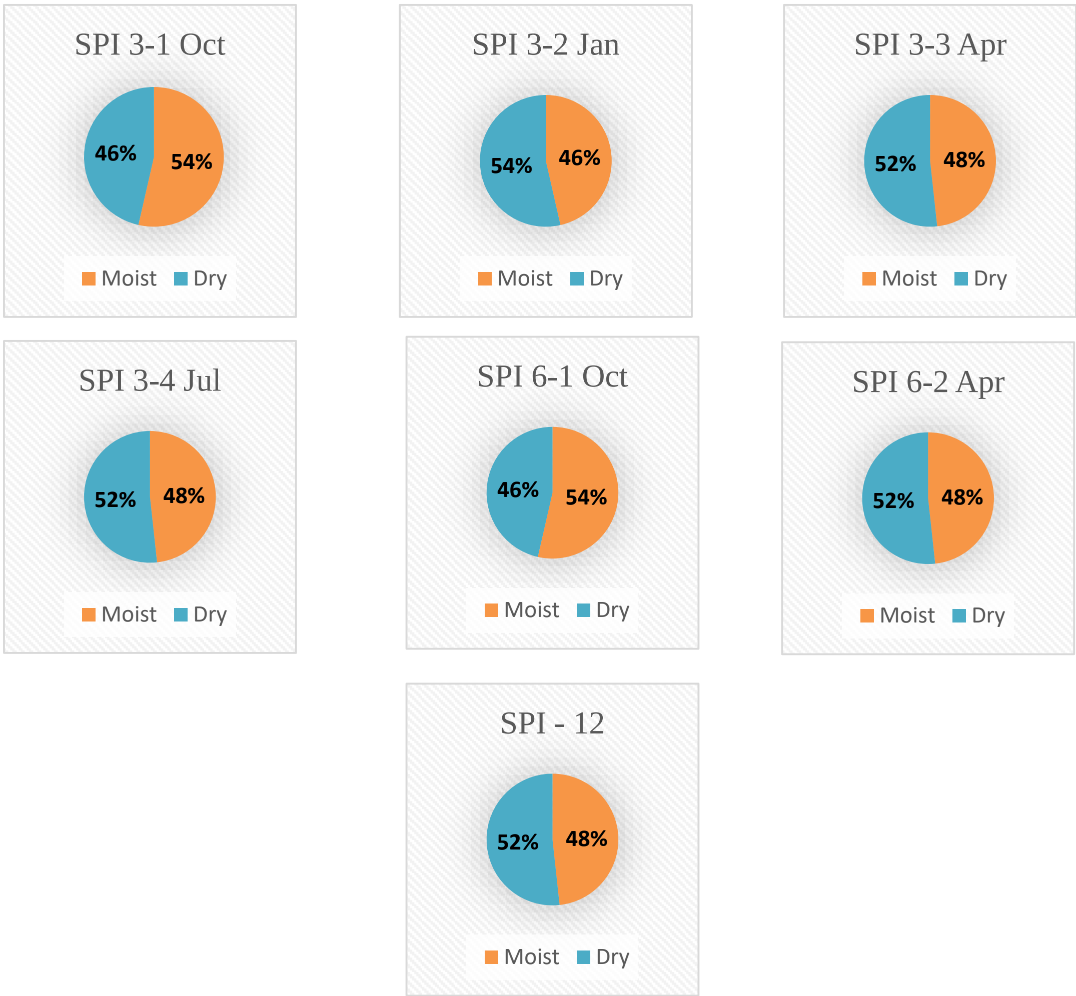

Figure 4.20. Dry - moist period distributions according to the 3,6,12 month SPI values for the Misurata station (No. 62016).

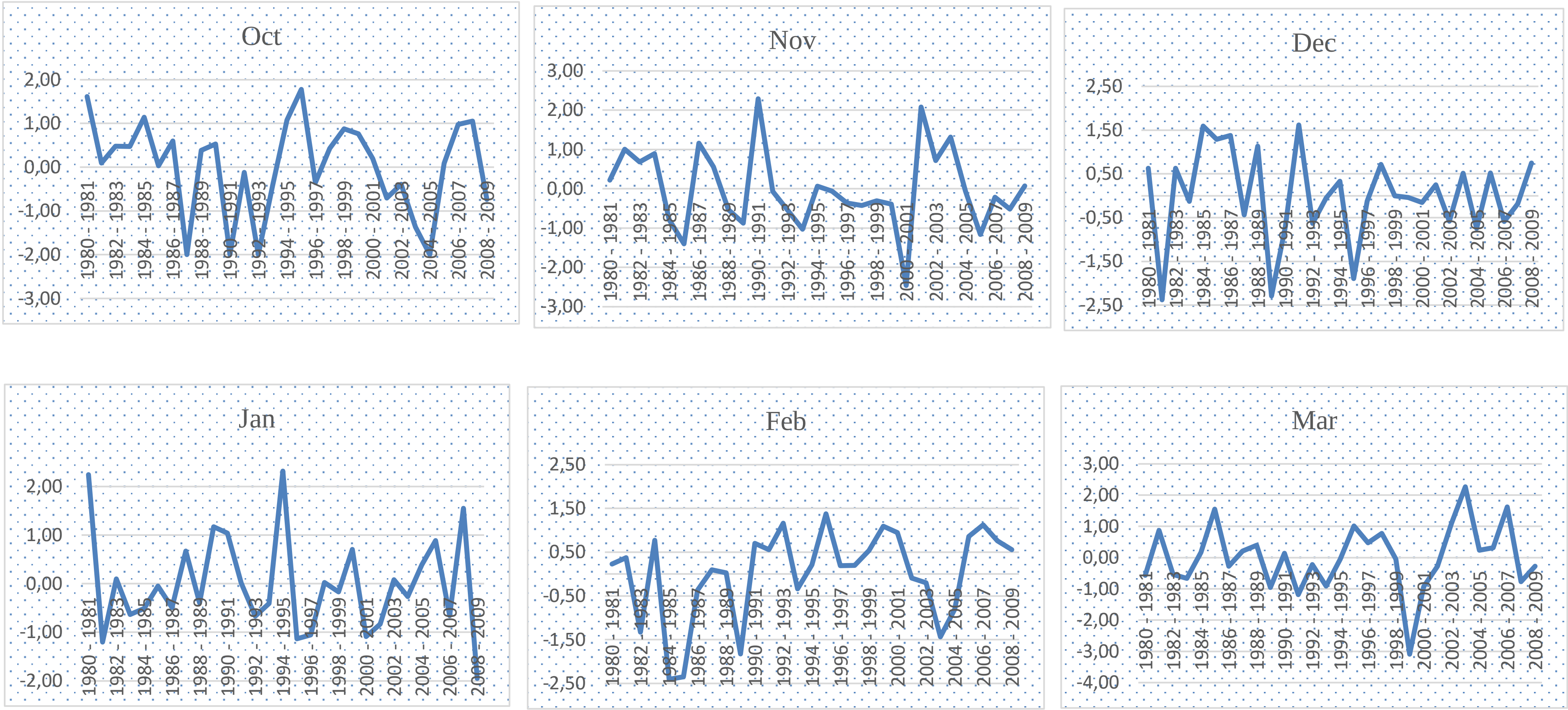

Figure 4.21. Temporal distribution of monthly SPI values of the Misurata station (No.62016).

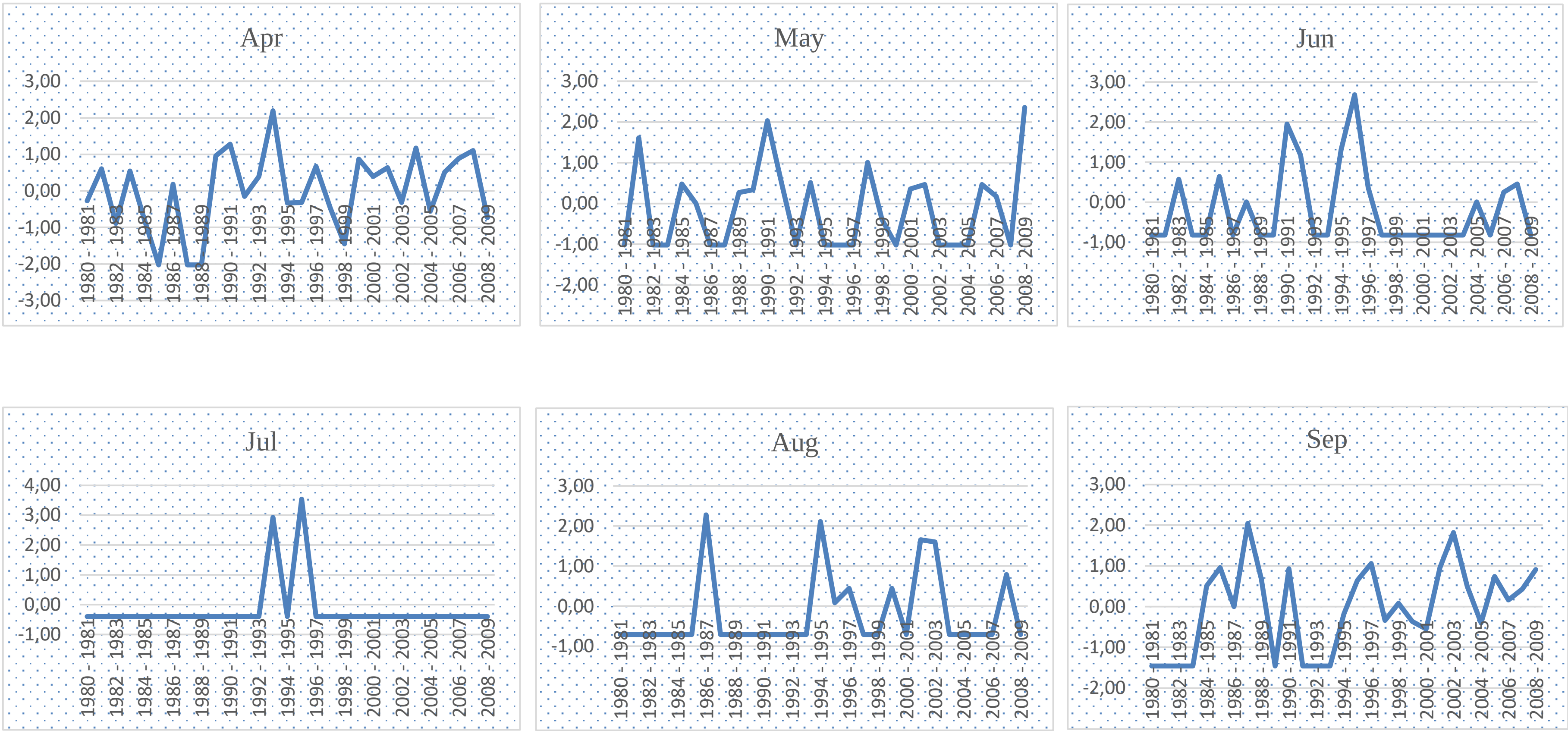

Figure 4.22. (Continued).

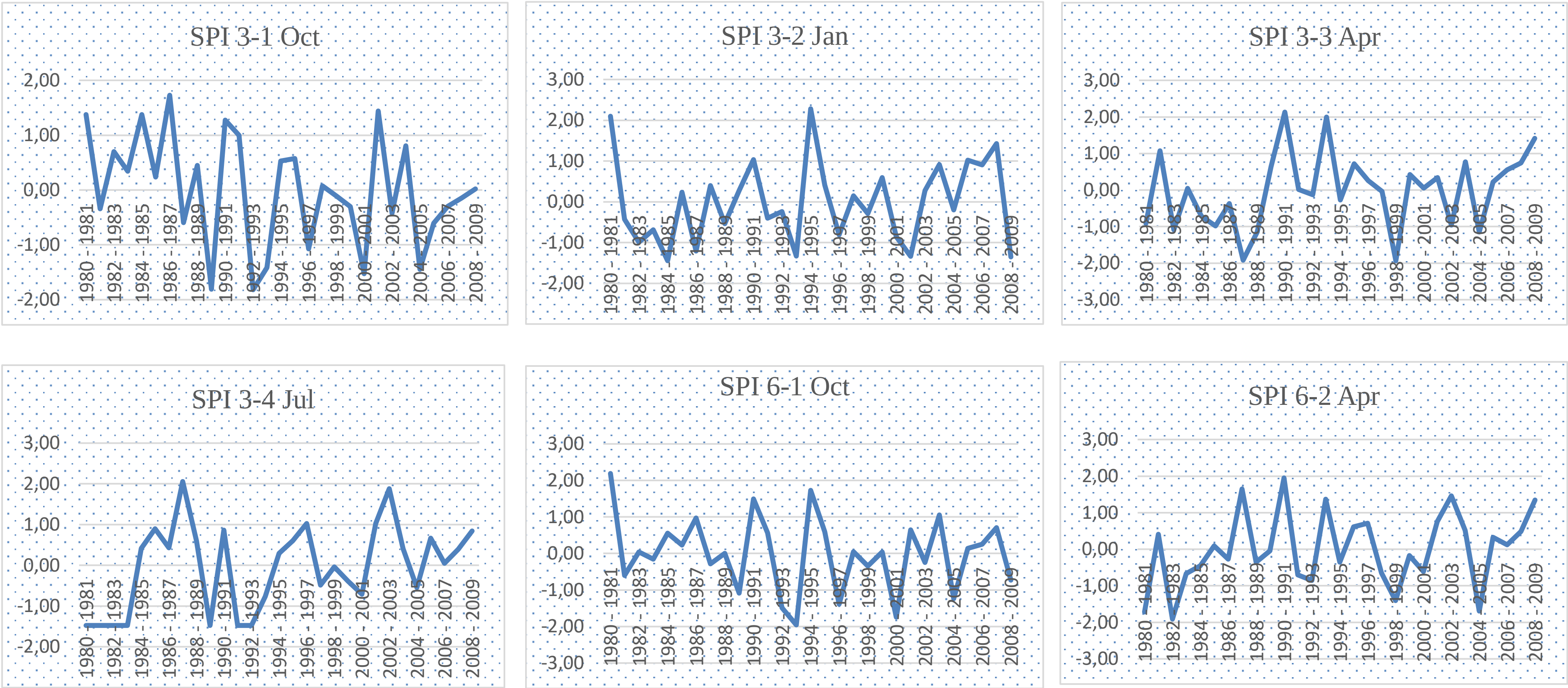

Figure 4.23. Temporal distribution of 3-, 6- and 12-month SPI values of the Misurata station (No.62016).

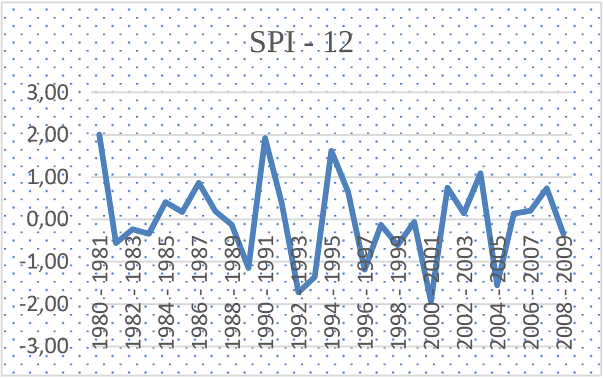

Figure 4.24. (Continued).

4.1.5. Sirt Station (62019) Meteorological Drought Analysis

Sirt Station computed using continuously measured monthly total precipitation data between periods 1980-2009, SPI values are examined during periods 1, 3, 6 and 12 months. The SPI values are calculated for the Sirt control station. Figure 4.17 and Figure 4.18 are shown the rates of monthly dryness and humidity 3- , 6-, and 12-months. In Figure 4.17, monthly dryness ranged between 32% and 76% according to SPI values. The highest dry period was 76% in June and 59% in September, with the lowest 32% dry period in February. The wet periods when analyzed were the period with a high moist of 68% in February, and the lowse wet period was 3% in July. The periods of drought and moisture for each of 3- , 6-, and 12 months for the SPI values are shown in Figure 4.18. The driest periods with the highest SPI -3 values are SPI3-4 in July of 59%, and the lowest dry period is SPI3-2 January with 43%. For the two periods of SPI of every six months SPI-6, the dry period was SPI6-1 October and SPI6-2 April with 52%. SPI-12 calculated according to 12-month values dryness is 55%, and moisture is 45%.

According to Figure 4.19, when the one-month SPI values obtained from the monthly total rainfall data for a 29-year period for the Sirt monitoring station are examined, the presence of near-normal was determined in July and August for a period of 28 years, while the highest drier period was in January 2008-2009, the highest moist period was July 2005-2006.

Figure 4.20 give the time distributions of SPI values for 3-, 6-, and 12-months, Examination of SPI values for 3 months SPI-3 October year 2000-2001 exceptional dry period, the year 1991-1992 exceptional moist period, SPI-3 January year 2008-2009 exceptional dry, the year 1992-1993 extremely moist, SPI-3 April 1983-1984 extremely dry period and the year 1990-1991 exceptional moist, SPI-3 July year 1980-1981 moderately dry, and the year 1985-1986 was identified as exceptional moist. When the SPI values are checked for 6 months, SPI-6 October year 2000-2001 is exceptionally dry, and SPI-6 April 1980-1981 is determined to be extremely dry. According to SPI-12 values, the year 2000-2001 was defined as exceptional dry and the year 1980-1981 extremely moist.

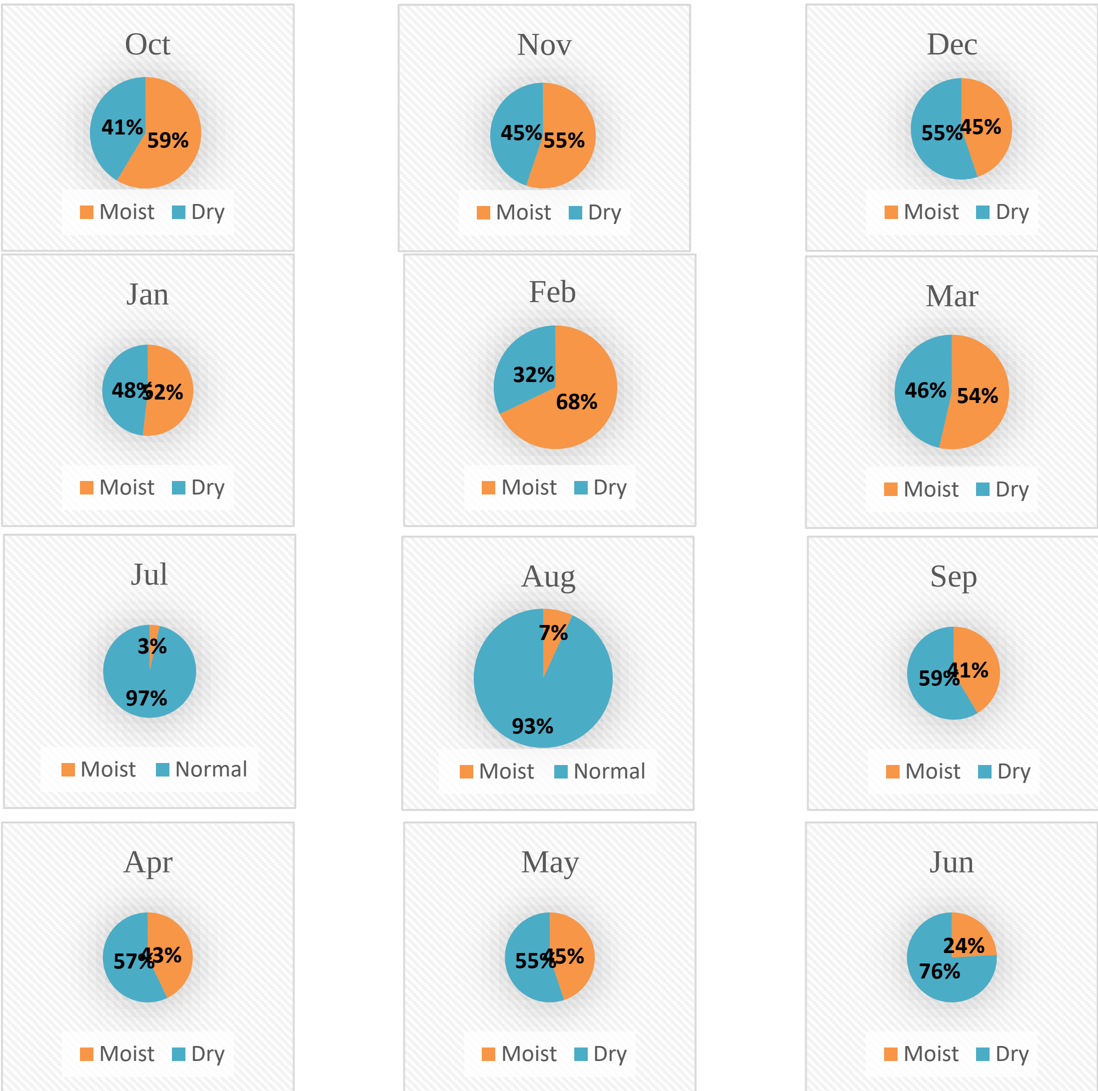

Figure 4.25. Dry - moist period distributions according to the monthly SPI values for the Sirt station No. 62019.

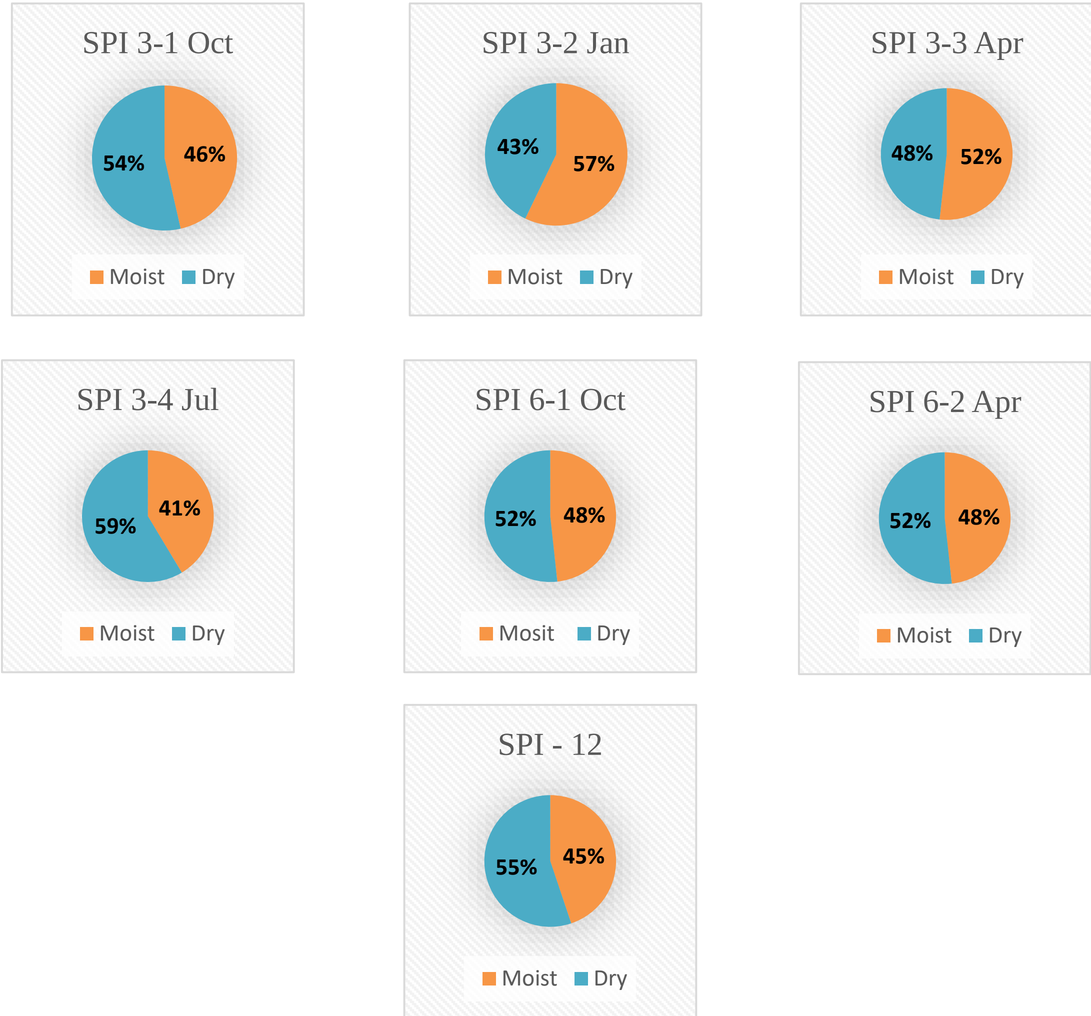

Figure 4.26. Dry - moist period distributions according to the 3,6,12month SPI values for the Sirt station (No. 62019).

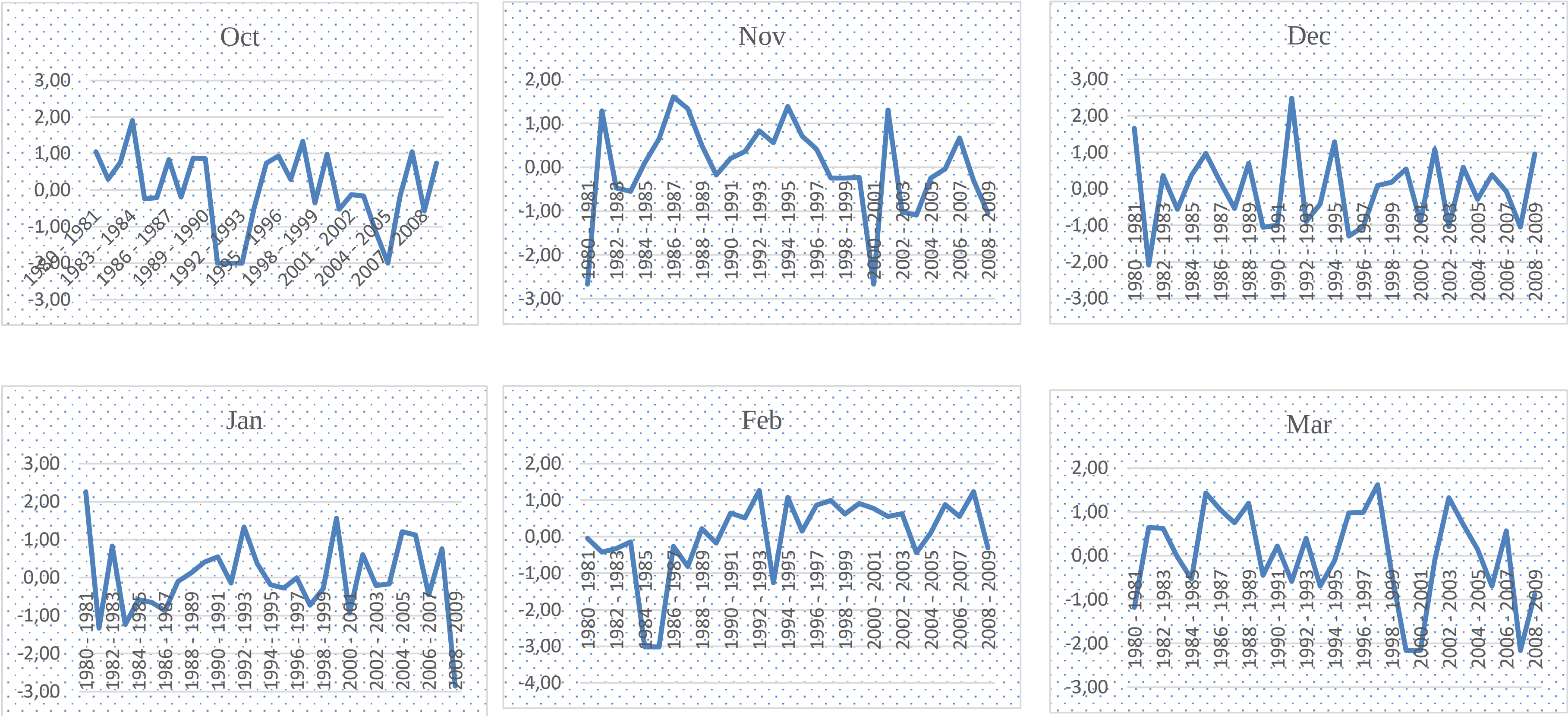

Figure 4.27. Temporal distribution of monthly SPI values of the Sirt station (No.62019).

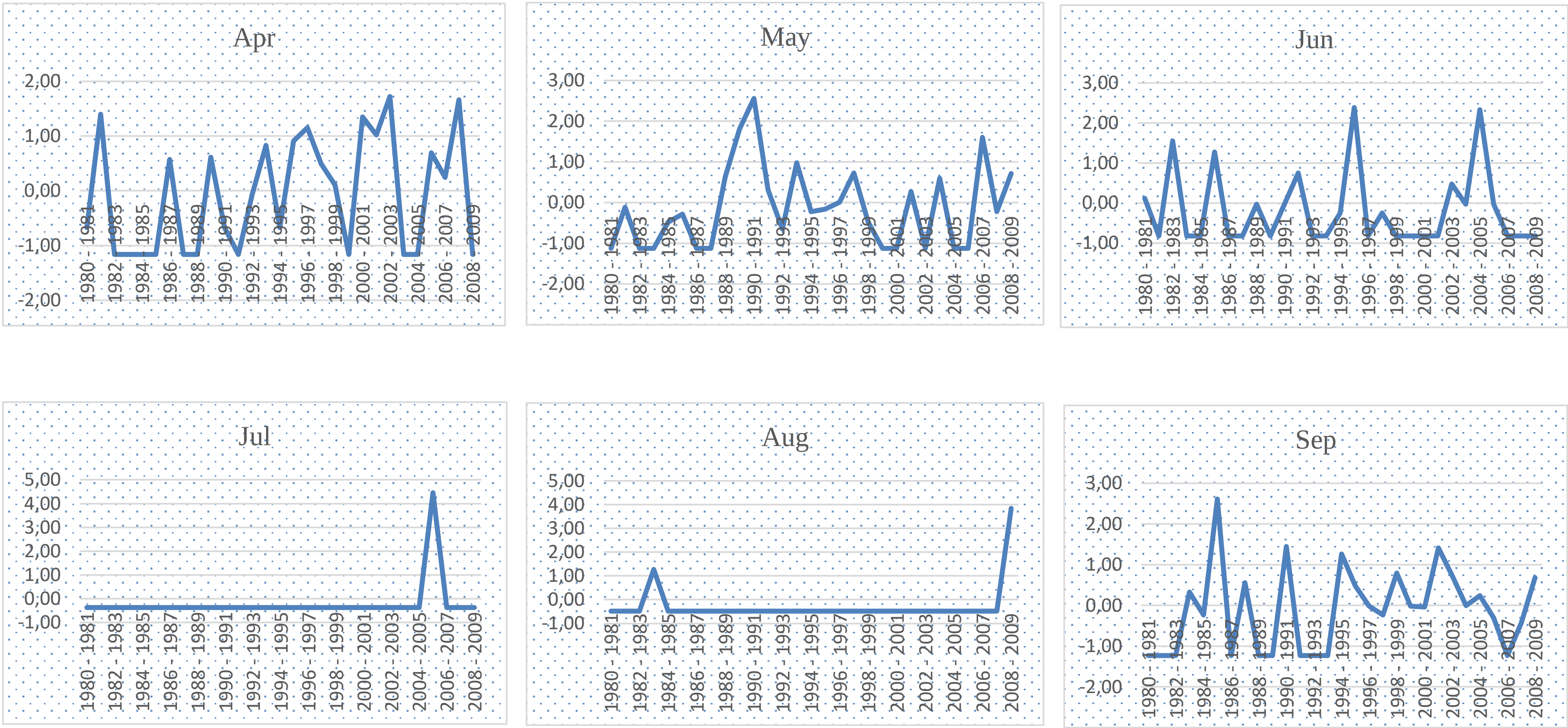

Figure 4.28. (Continued).

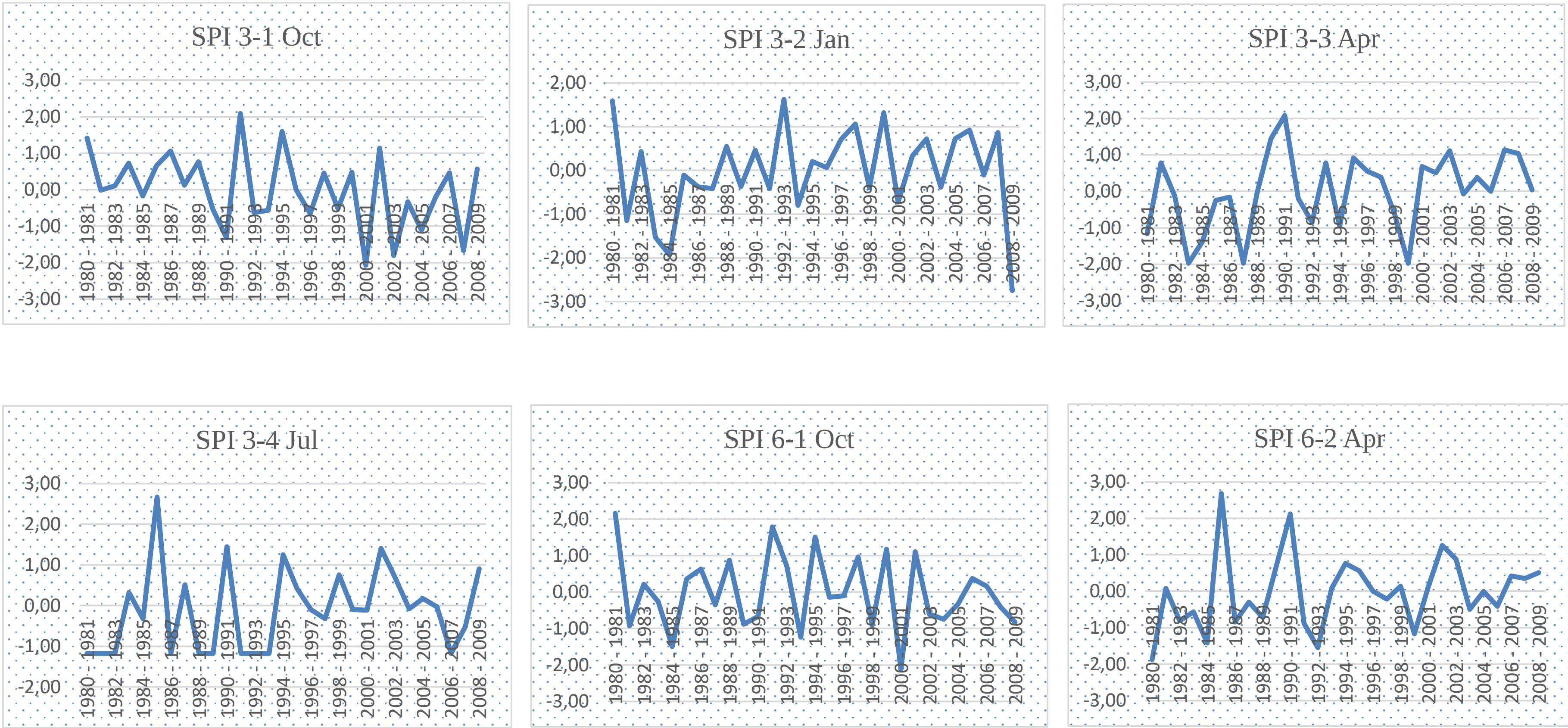

Figure 4.29. Temporal distribution of 3-, 6-, and 12 month SPI values of the Sirt station (No.62019).

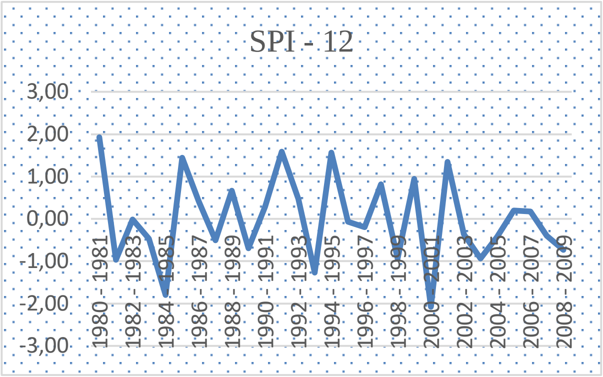

Figure 4.30. (Continued).

4.1.6. Zuara Station (62007) Reconnaissance Drought Analysis

Zuara Station computed using monthly total precipitation and mean monthly temperature continuously measured data between the periods 1980-2008, RDI values are examined during periods 1-, 3-, 6-, and 12 months. According to Figure 4.21, when the one-month RDI values obtained from the monthly total rainfall and mean monthly temperature data for a 29-year period for the Zuara monitoring station are examined, the presence of an exceptional drought is determined in November and December year 2000-2001 and in March year 2005-2006. The highest drought value (-3.03) was recorded in November 2000-2001.In July, all years are near normal except the year 1985-1986 exceptionally moist.

Figure 4.22 time distributions of RDI values for 3-, 6-, and 12-months, Examination of RDI values for 3 months RDI-3 October year 1981-1982 extremely dry period, RDI-3 January year 1980- 1981 extremely dry, RDI-3 April 1998-1999 exceptionally dry period. When the RDI values are checked for 6 months, RDI-6 October year 1981-1982 and 2000-2001 is extremely dry, and RDI-6 April 1980-1981 and 1988-1989 and 1998-1999 is determined to be extremely dry. According to RDI-12 years 1981-1982 were extremely dry. The year 2000-2001 is considered one of the driest years in this station. The drought RDI value reached -2.25 and is often repeated. Drought in this station after a year or two during the study period.

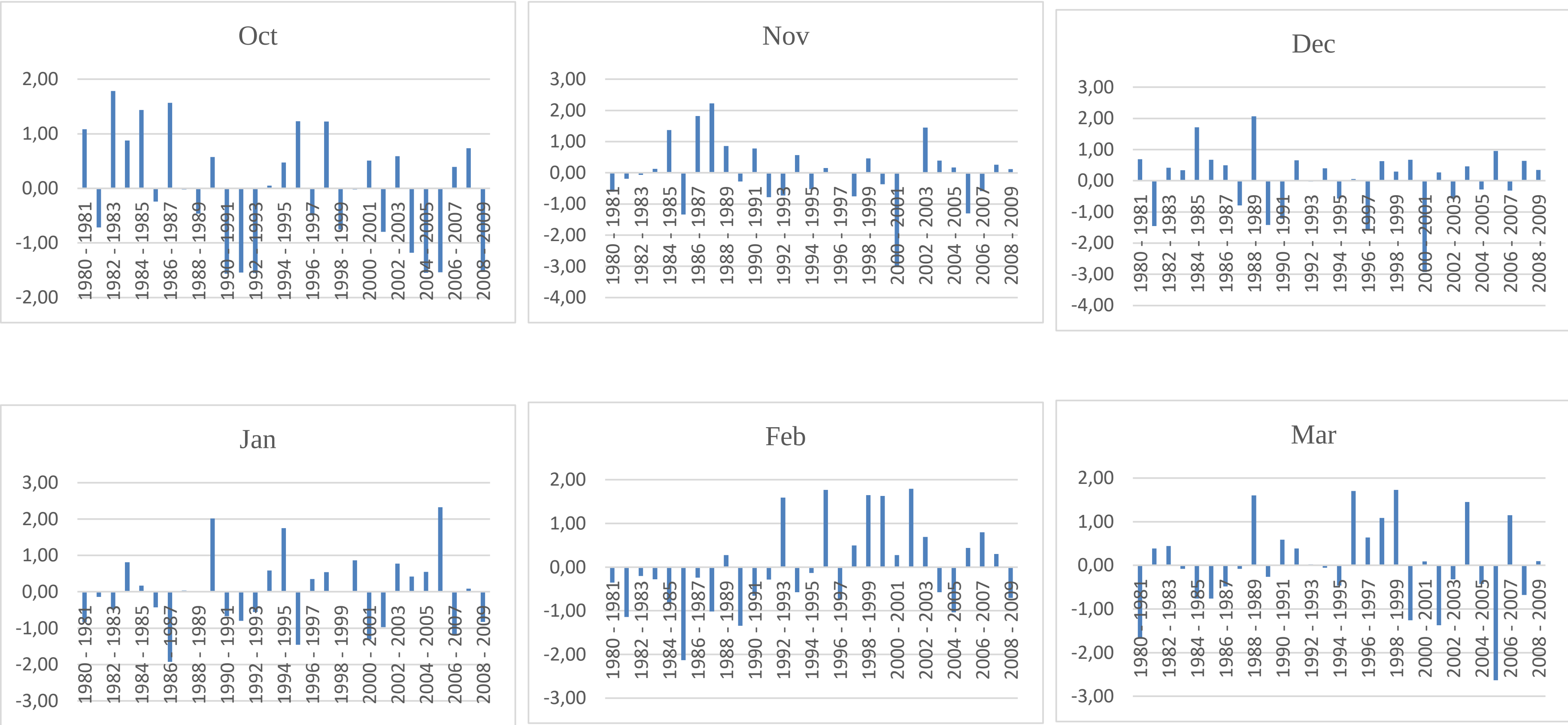

Figure 4.31. Dry - moist period distributions according to the monthly RDI values for the Zuara station (No. 62007).

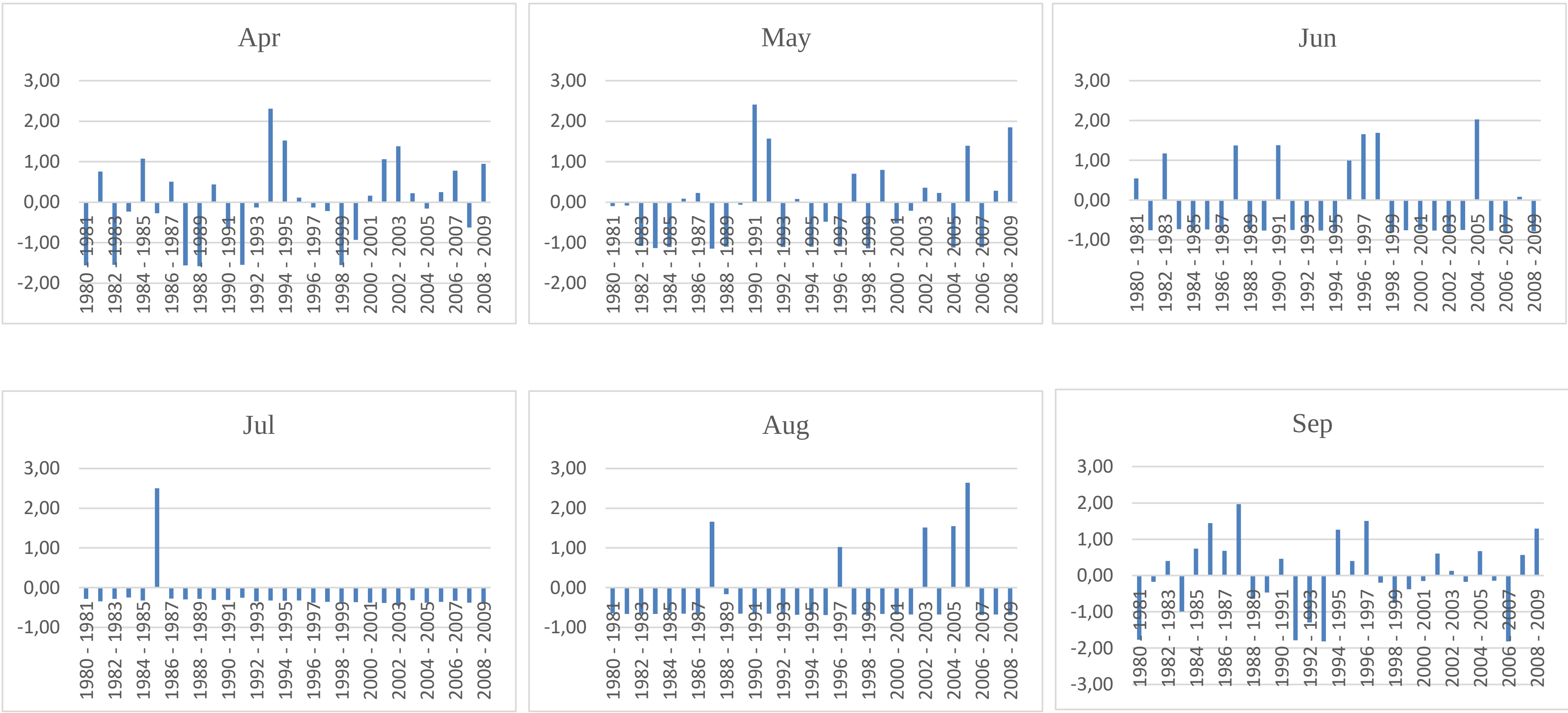

Figure 4.32. (Continued).

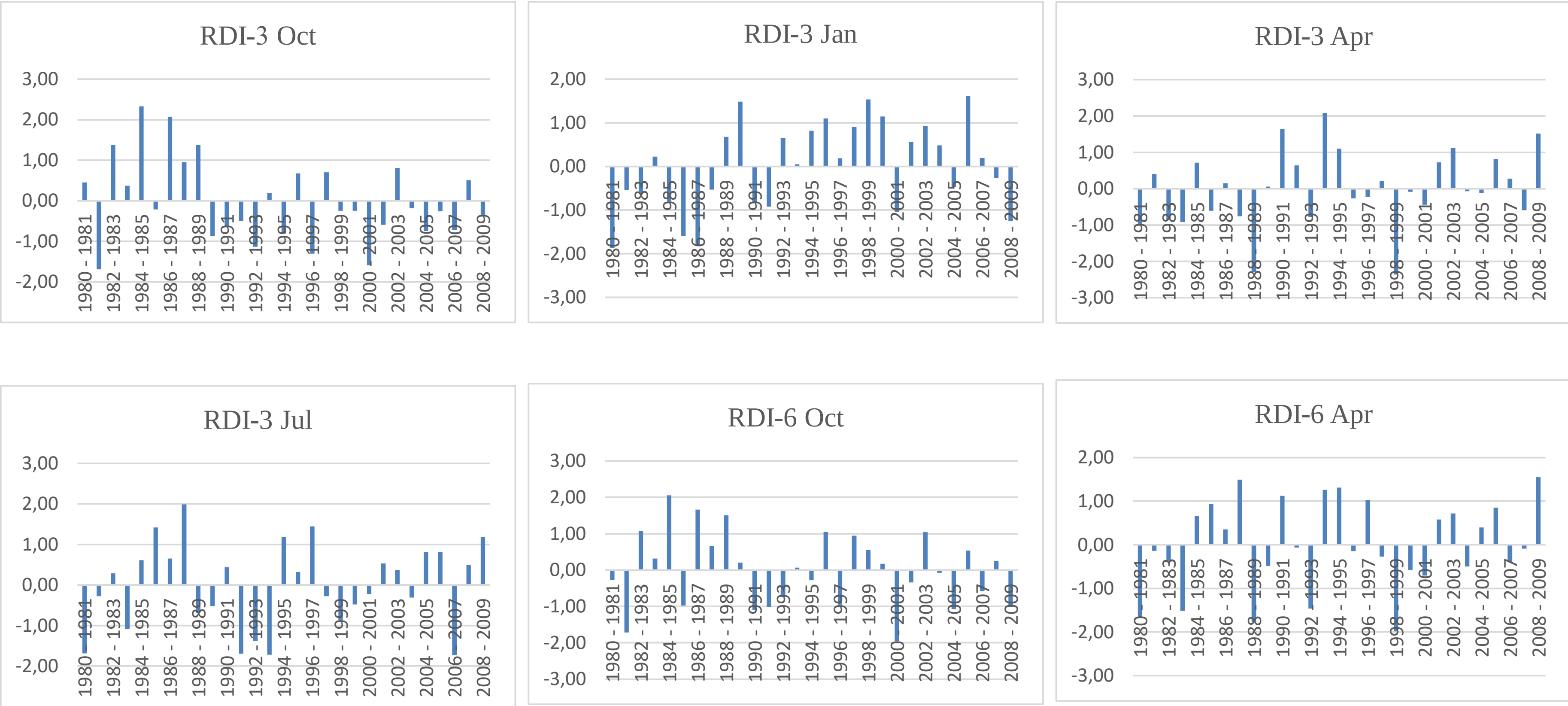

Figure 4.33. Dry - moist period distributions according to the 3-,6-,12 months RDI values for the Zuara station (No. 62007).

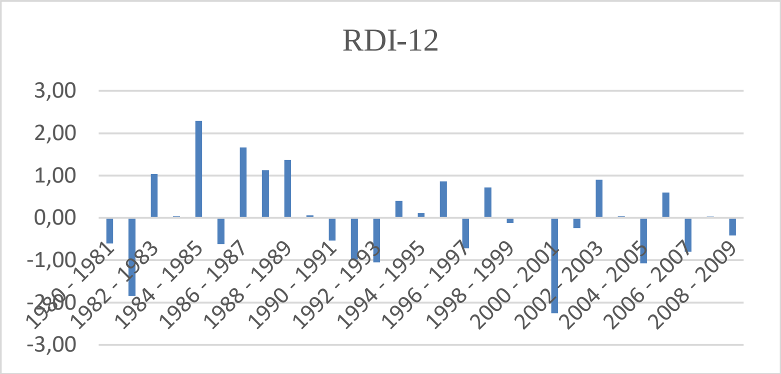

Figure 4.34. (Continued).

4.1.7. Tripoli Airport Station (62010) Reconnaissance Drought Analysis

Tripoli Airport station, computed using monthly total precipitation and mean monthly temperature continuously measured data between 1980-2008, RDI values were examined during periods 1-, 3-, 6- and 12 monthly. According to Figure 4.23, when the one-month RDI values obtained from the monthly total rainfall and mean monthly temperature data for a 29-year period for the Tripoli Airport monitoring station are examined, the presence of an extreme drought was determined in December 1989-1990 and in March 2007-2008. The highest drought value (-2.98) was recorded in November 2000-2001. In July, most years are abnormally dry.

Figure 4.24 gives that the time distributions of RDI values for 3-, 6- and 12-months, Examination of RDI values for 3 months RDI-3 October year 2000-2001 extremely dry period, RDI- 3 January year 2008- 2009 extremely dry, RDI-3 April 1998-1999 extremely dry period. When the RDI values are checked for 6 months, RDI-6 October year 2000-2001 is extremely dry and RDI-6 April 1998-1999 is determined to be exceptionally dry. According to RDI-12, the year 2000-2001 is considered one of the driest years in this station. The drought RDI value reached -2.04.

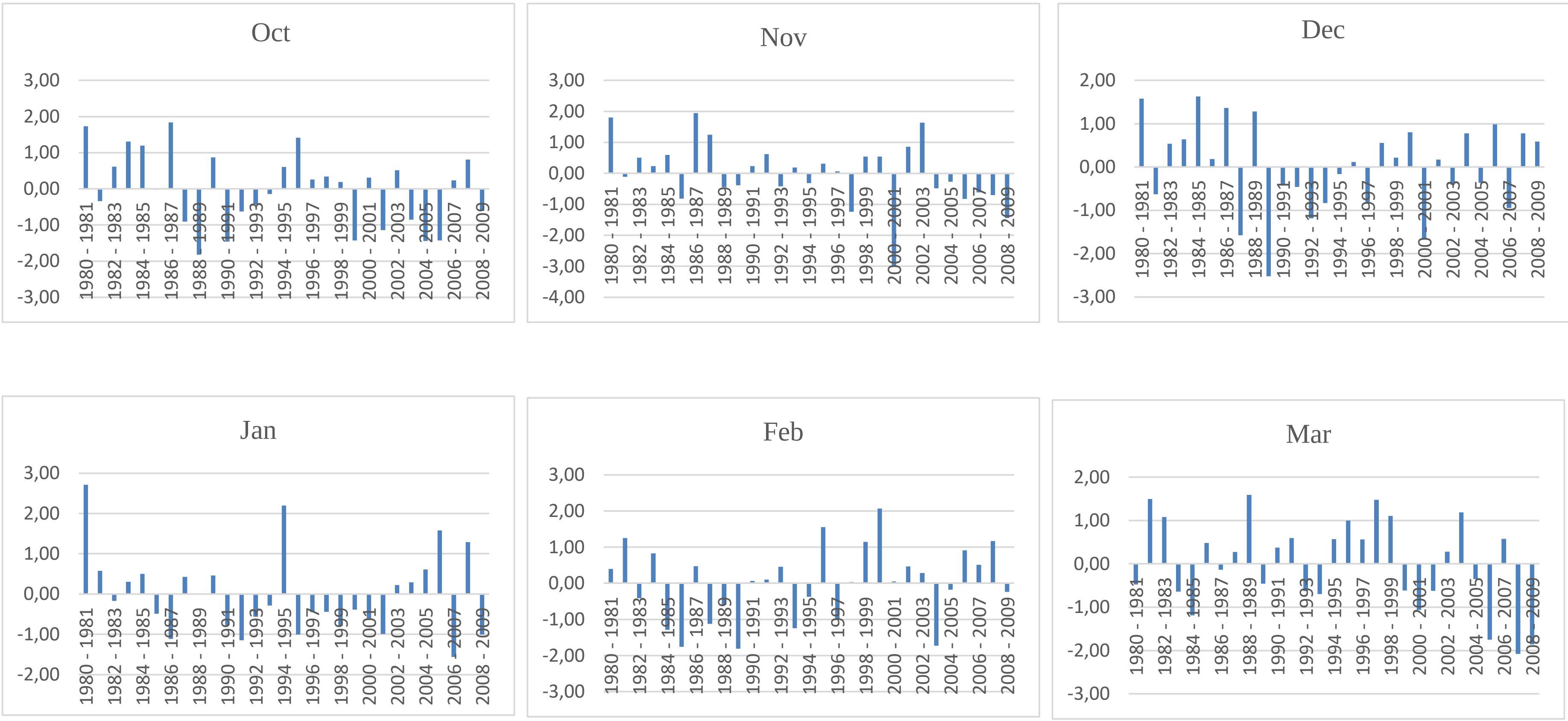

Figure 4.35. Dry - moist period distributions according to the monthly RDI values for the Tripoli Airport station (No. 62010).

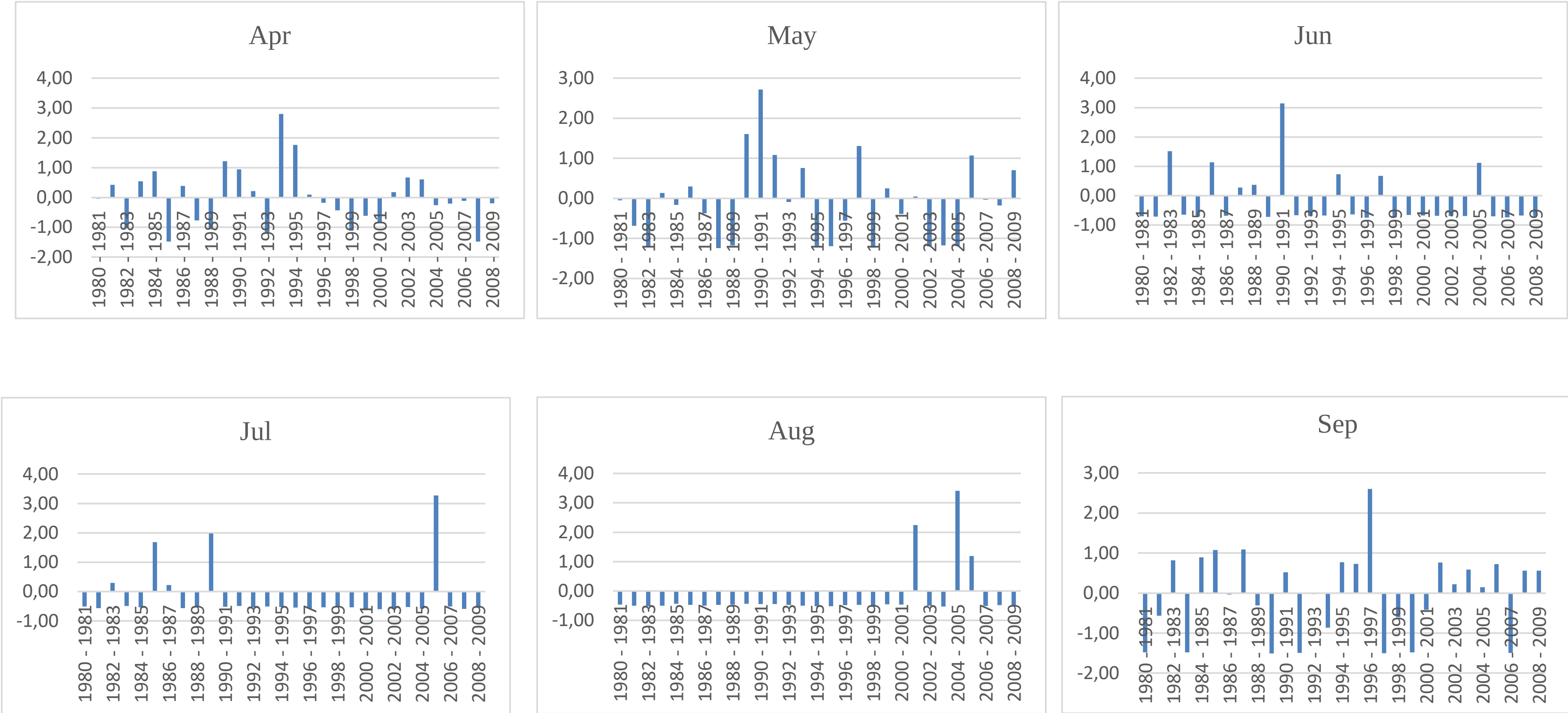

Figure 4.36. (Continued).

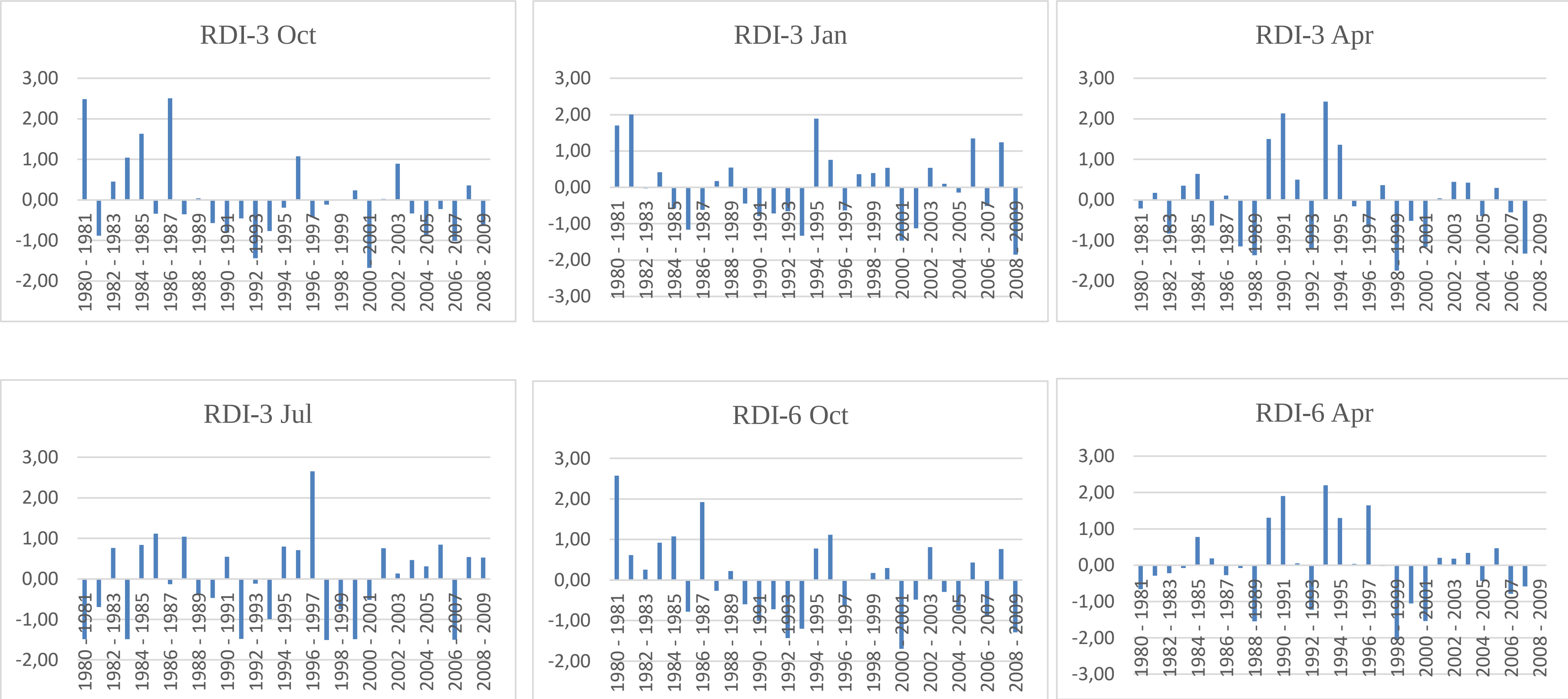

Figure 4.37. Dry - moist period distributions according to the 3-, 6-,12 months RDI values for the Tripoli Airport station (No. 62010).

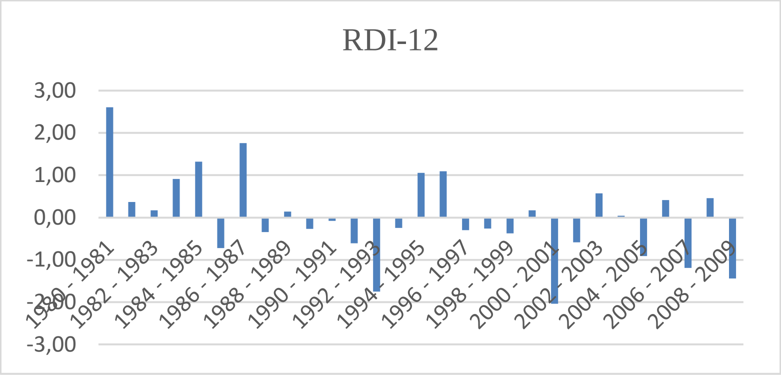

Figure 4.38. (Continued).

4.1.8. Nalut Station (62002) Reconnaissance Drought Analysis

Nalut Station computed using monthly total Precipitation and mean monthly temperature continuously measured data between 1980-2008, RDI values are examined during periods 1-, 3-, 6-, and 12- months. According to Figure 4.25, when the one-month RDI values obtained from the monthlytotal rainfall and mean monthly temperature data for a 29-year period for the Nalut monitoring station are examined, the presence of an extremely drought is determined in December 2000-2001, and the presence of extreme drought was determined in January 2006-2007. The highest drought value (-2.56) was recorded in December 2000-2001. Figure 4.26 Time distributions of RDI values for 3-, 6- and 12-months, Examination of RDI values for 3 months RDI-3 October year 1981-1982 exceptionally dry period, RDI-3 January year 2004-2005 exceptionally dry, RDI-3 April 1998-1999 exceptionally dry period, RDI-3 July year 1982-1983 severely dry. When the RDI values are checked for 6 months, RDI-6 October year 1992-1993 is extremely dry and RDI-6 April 1983-1984 is determined to be exceptionally dry. According to RDI-12, the year 1992-1993 is considered one of the driest years in this station. The drought RDI value reached -2.13.

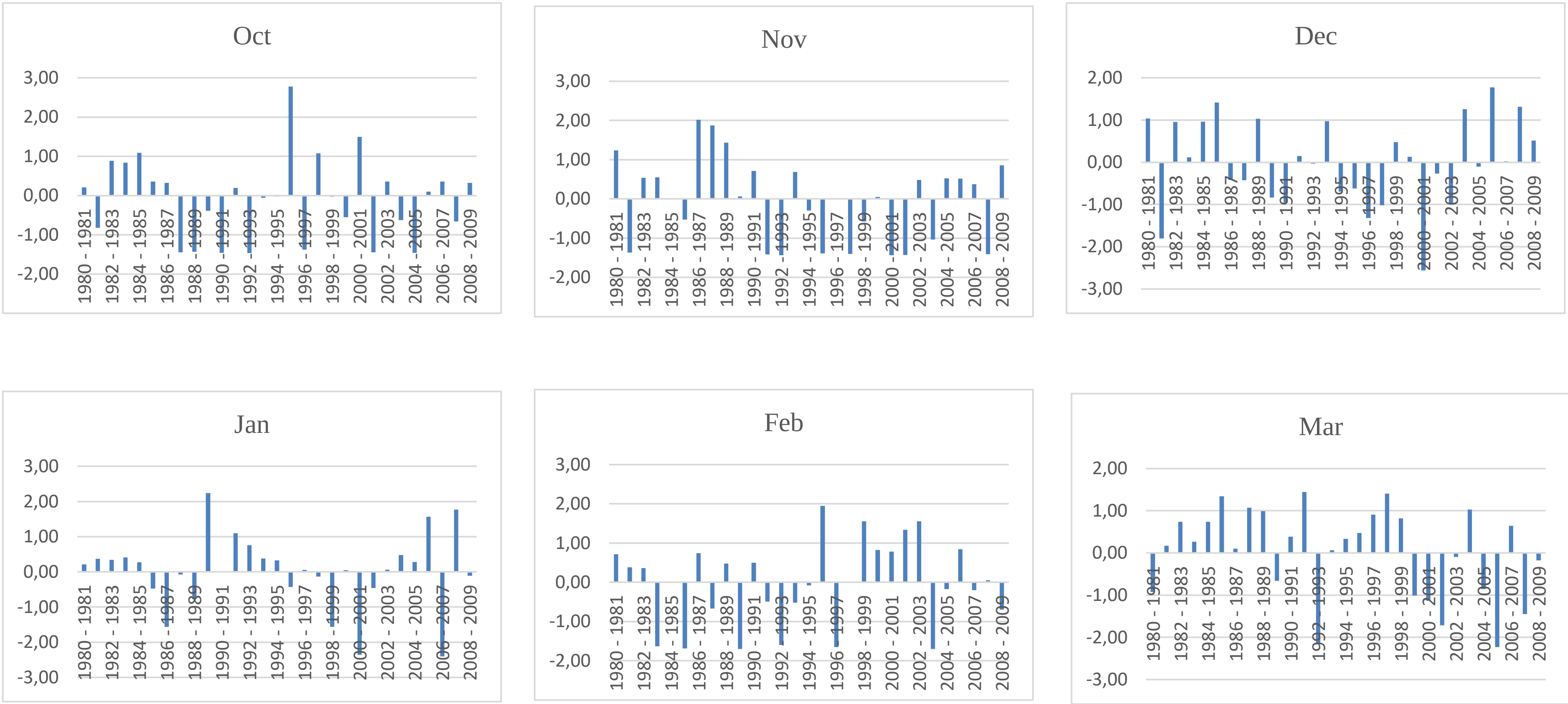

Figure 4.39. Dry - moist period distributions according to the monthly RDI values for the Nalut station (No. 62002).

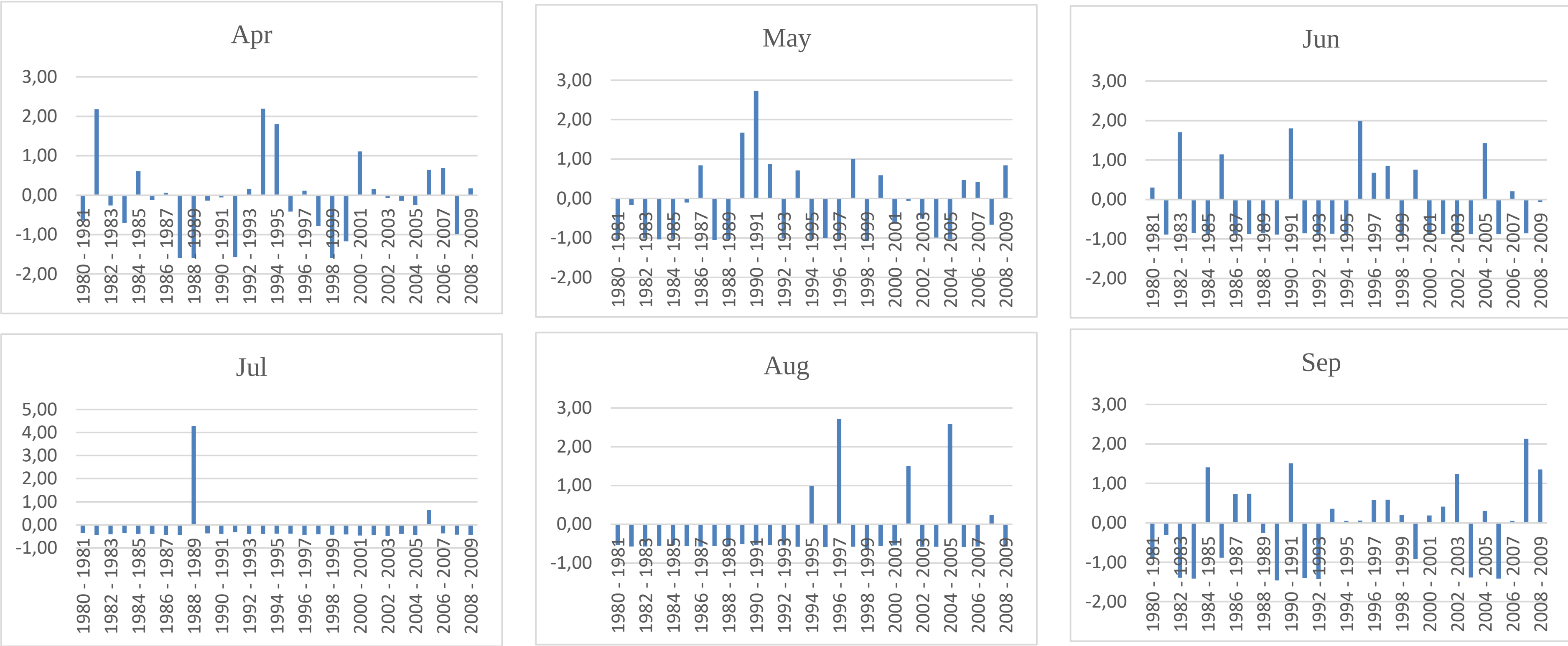

Figure 4.40. (Continued).

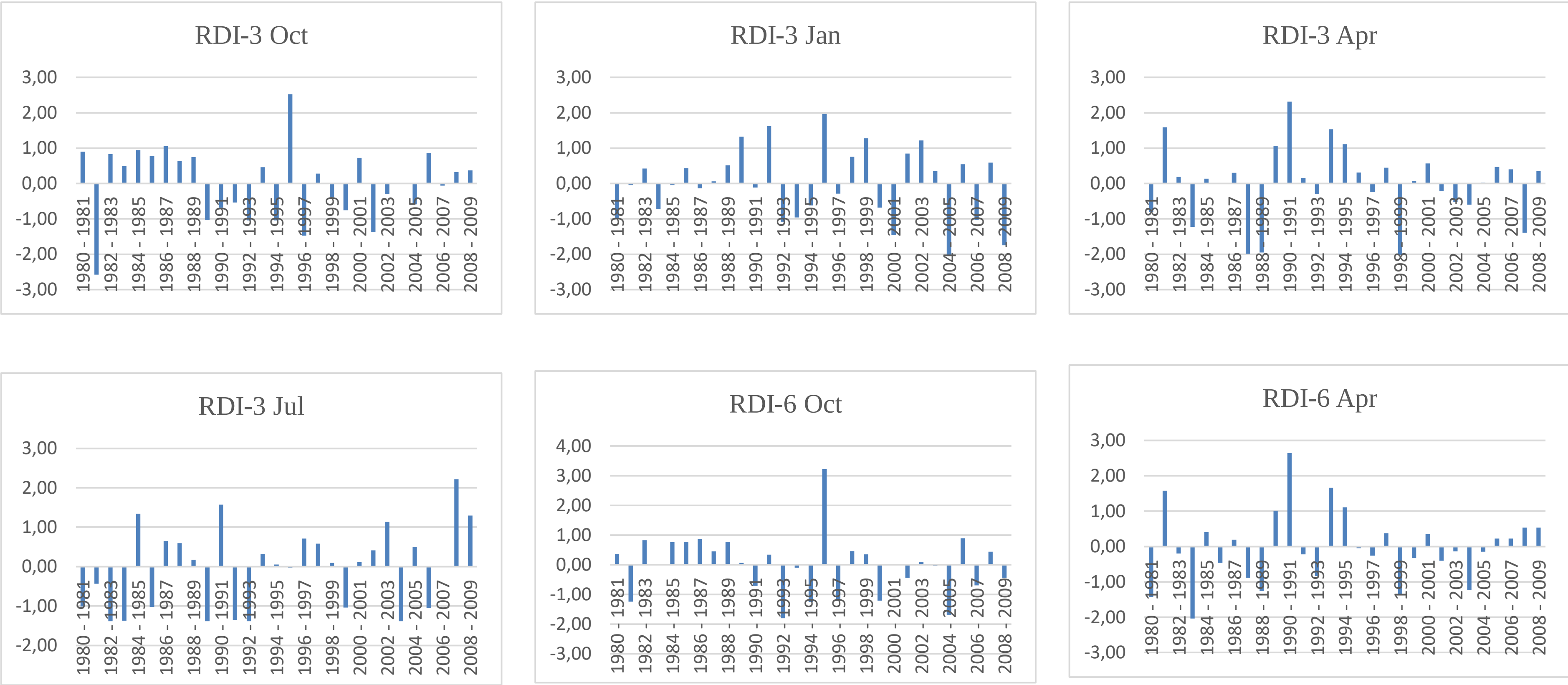

Figure 4.41. Dry - moist period distributions according to the 3-, 6-,12 months RDI values for the Nalut station (No. 62002).

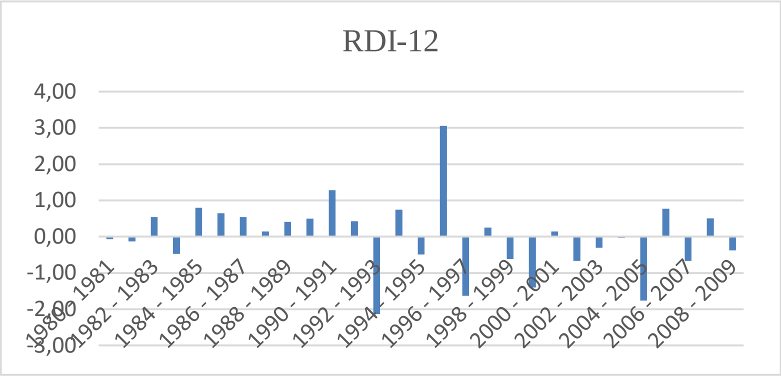

Figure 4.42. (Continued).

4.1.9. Misurata Station (62016) Reconnaissance Drought Analysis

Misurata Station computed using monthly total precipitation and mean monthly temperature continuously measured data between periods 1980-2008, RDI values are examined during periods 1-, 3-, 6-, and 12- months. According to Figure 4.27, when the one-month RDI values obtained from the monthlytotal rainfall and mean monthly temperature data for a 29-year period for the Misurata monitoring station were examined, the presence of an exceptionally dry is determined in November 2000-2001 and December 1989-1990 and in February 1985-1986. The highest drought value (-3.03) was recorded in March 1999-2000.

Figure 4.28 gives the time distributions of RDI values for 3-, 6- and 12-months, Examination of RDI values for 3 months RDI-3 October year 1992-1993 extremely dry period, RDI-3 January year 1984-1985 severely dry, RDI-3 April 1998-1999 extremely dry period, RDI-3 July year 1989-1990 and 1992-1993 severely dry. When the RDI values are checked for 6 months, RDI-6 October 1993-1994 is exceptionally dry and RDI-6 April 2004-2005 is extremely dry. According to RDI-12, The year 2000-2001 is considered one of the driest years in this station. The drought RDI value reached -2.02.

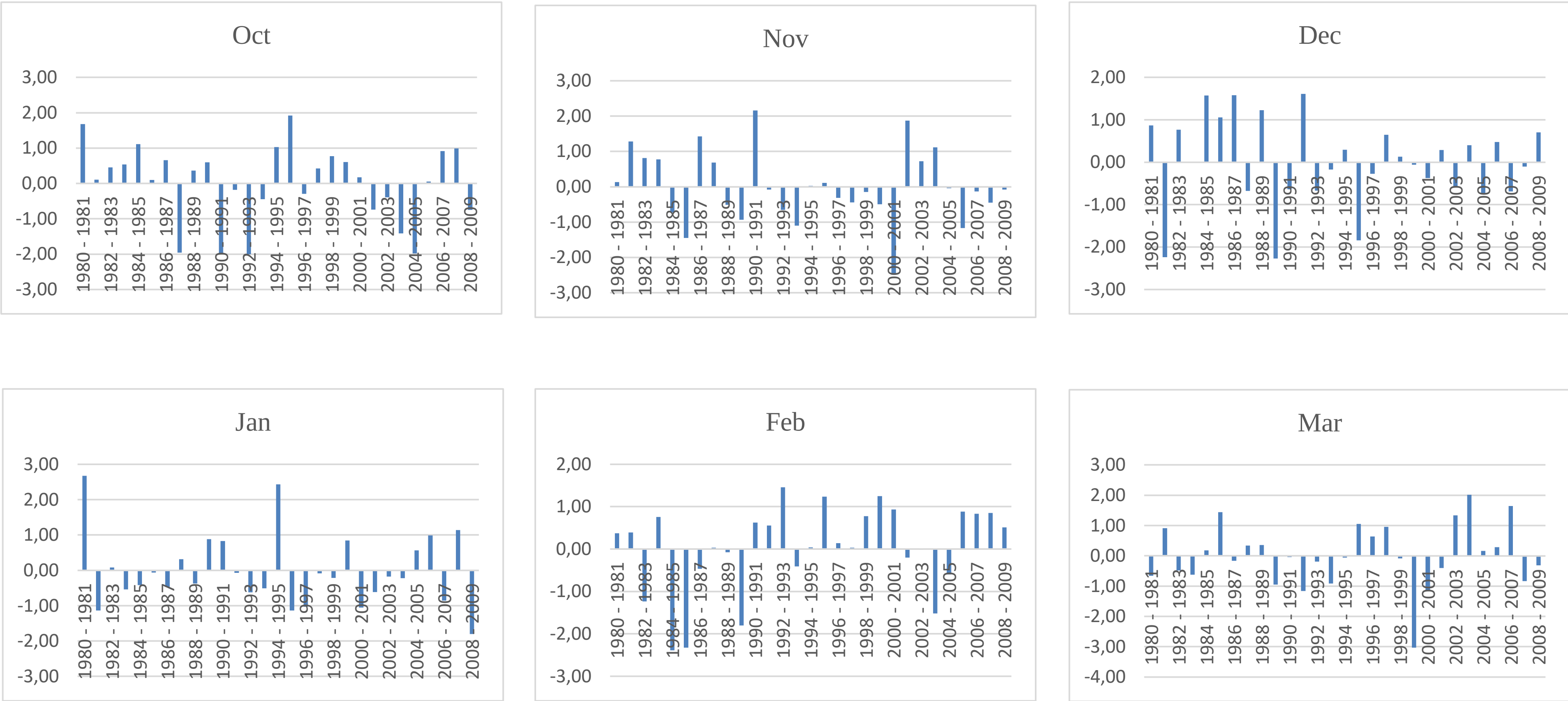

Figure 4.43. Dry - moist period distributions according to the monthly RDI values for the Misurata station (No. 62016).

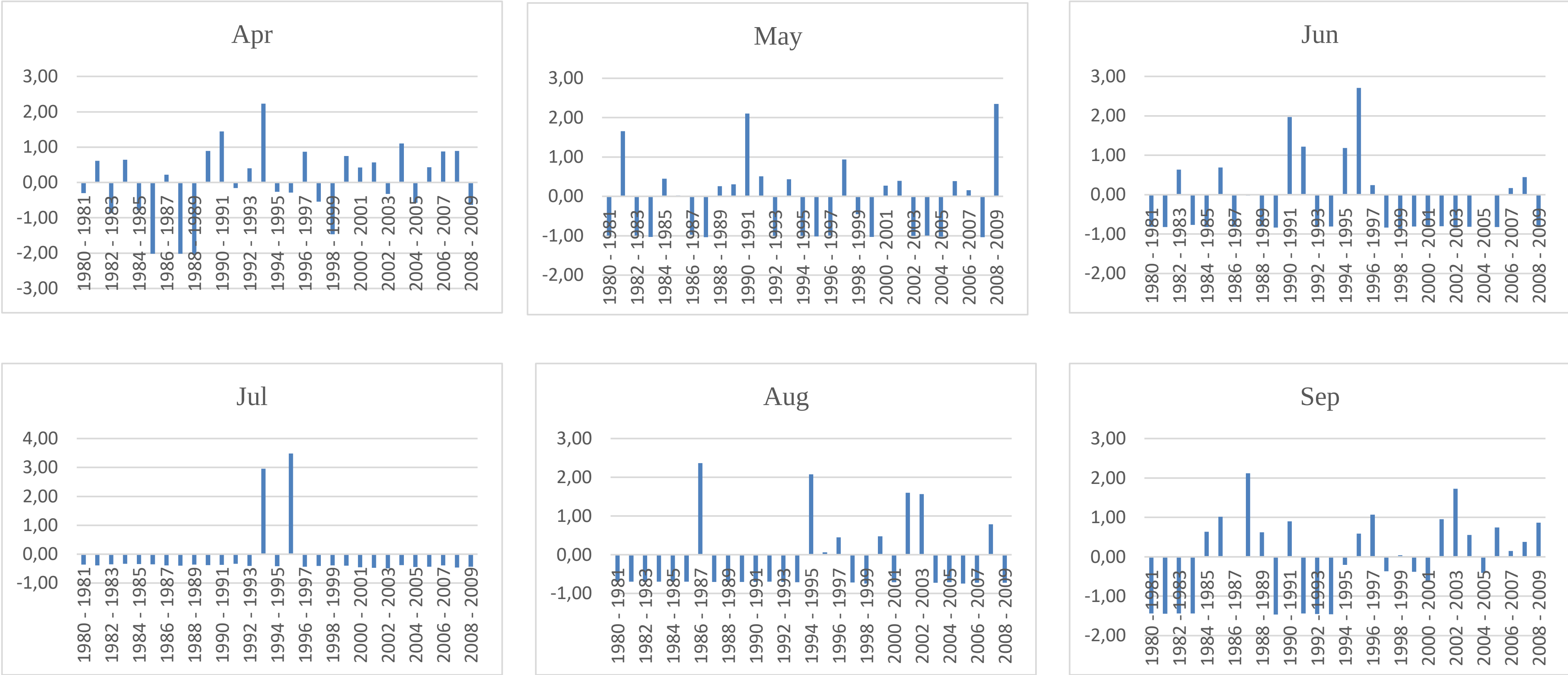

Figure 4.44. (Continued).

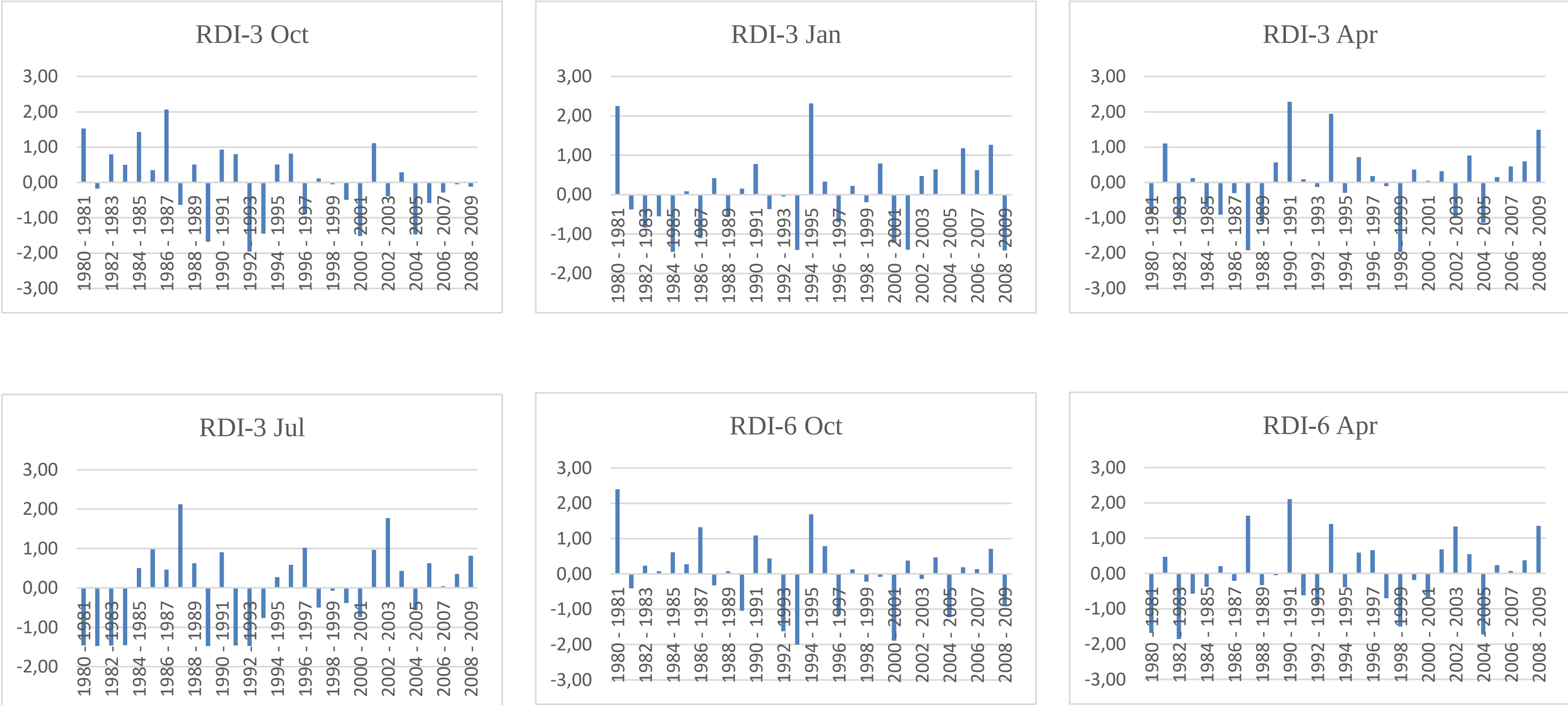

Figure 4.45. Dry - moist period distributions according to the 3-,6-,12 months RDI values for the Misurata station (No. 62016).

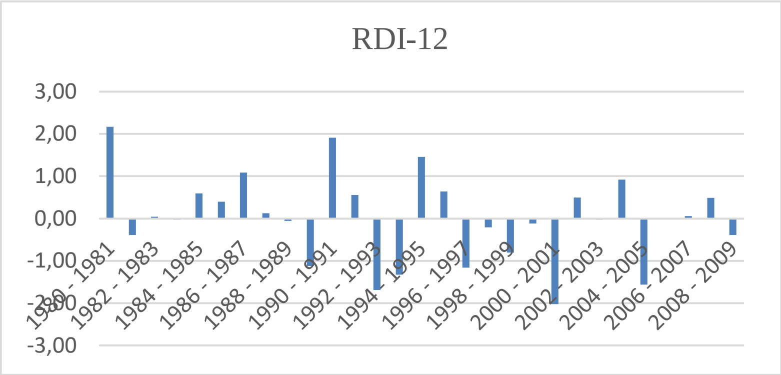

Figure 4.46. (Continued).

4.1.10. Sirt Station (62019) Reconnaissance Drought Analysis

Sirt Station computed using monthly total precipitation and mean monthly temperature continuously measured data between periods 1980-2008, RDI values are examined during periods 1-, 3-, 6-, and 12- months. According to Figure 4.29, when the one-month RDI values obtained from the monthlytotal rainfall and mean monthly temperature data for a 29-year period for the Sirt monitoring station are examined, the presence of an exceptionally dry was determined in November 1980-1981 and in January 2008-2009. The highest drought value (-2.95) was recorded in February 1984-1985. Figure 4.30 shows that the Time distributions of RDI values for 3-, 6-, and 12- months, Examination of RDI values for 3 months RDI-3 October year 2000-2001 exceptionally dry period, RDI-3 January year 2008- 2009 exceptionally dry, RDI-3 April 1987-1988 exceptionally dry period. When the RDI values are checked for 6 months, RDI-6 October year 2000-2001 is exceptionally dry and RDI-6 April 1980-1981 is determined to be extremely dry. According to RDI-12, the year 2000-2001 is considered one of the driest years in this station. The drought RDI value reached -2.11.

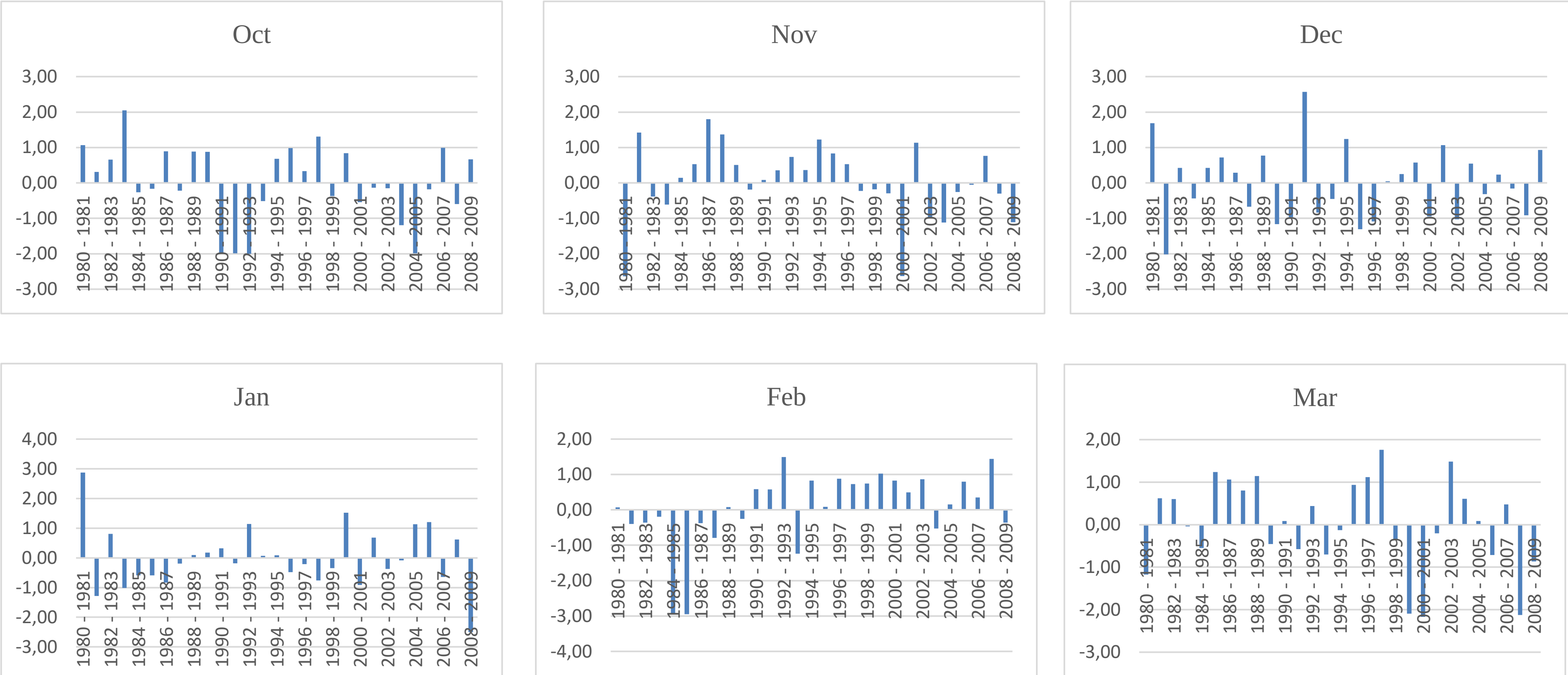

Figure 4.47. Dry - moist period distributions according to the monthly RDI values for the Sirt station (No. 62019).

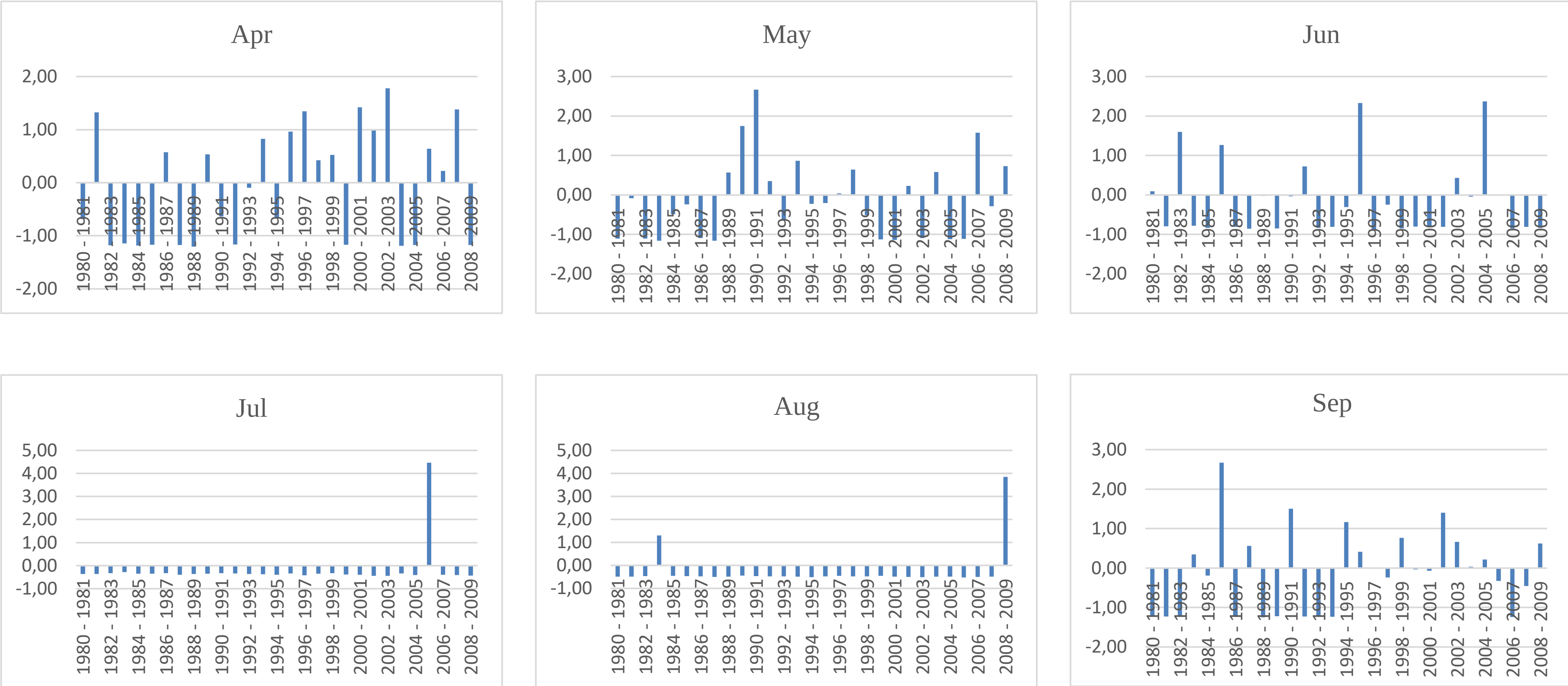

Figure 4.48. (Continued).

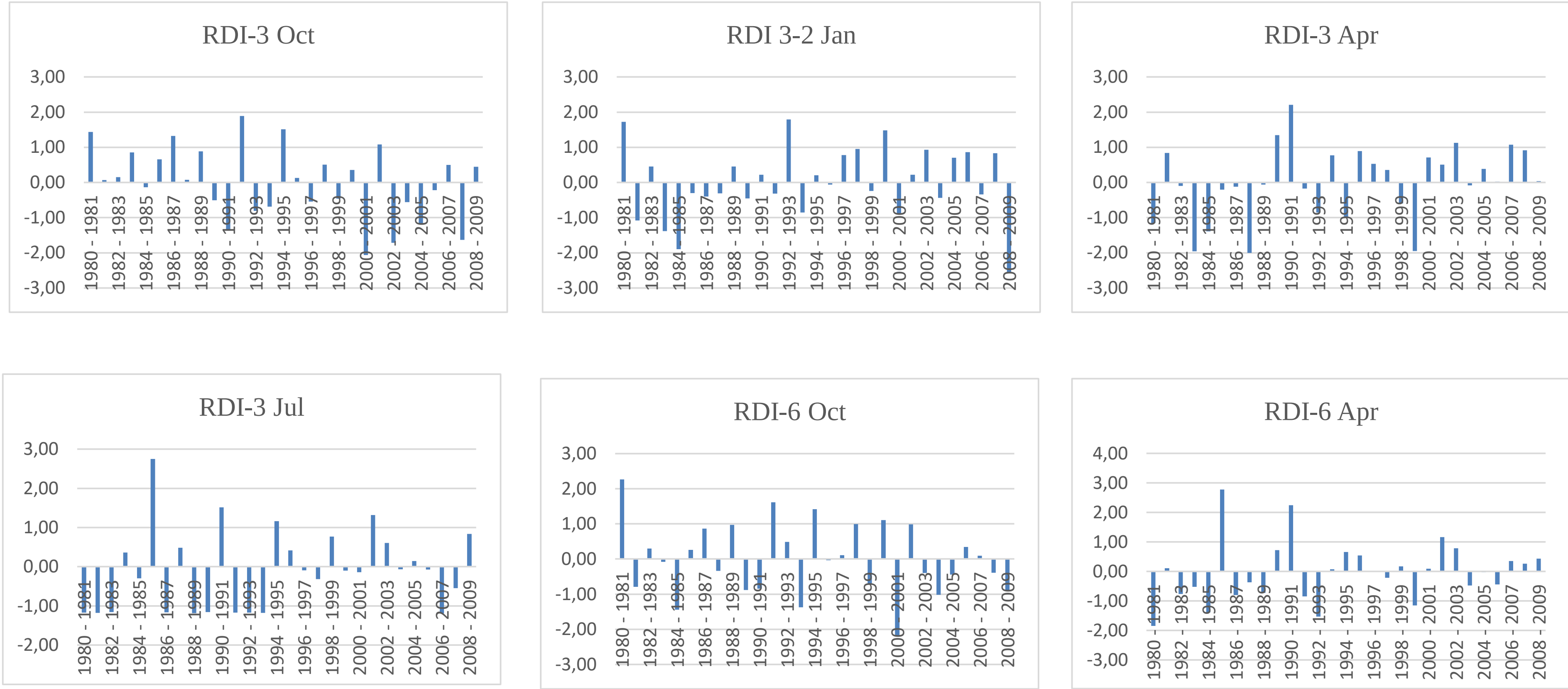

Figure 4.49. Dry - moist period distributions according to the 3-,6-,12 month RDI values for the Sirt station (No. 62019).

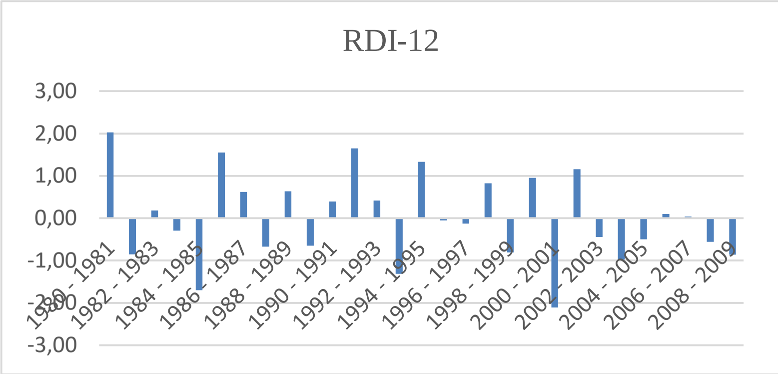

Figure 4.50. (Continued).

Table 4.1. The abstract of SPI results of all stations.

		Zuara	Tripoli Airport	Nalut	Misurata	Sirt
Monthly	Range of Dry %	48% - 79%	46% - 86%	45% - 86%	39% - 79%	32% -76%
	The highest Dry period	79% August, 71% Jun	86% July, 76% Jun	86% August, 69% Jun	79% August, 71% Jun	76% Jun, 59% Sep
	The lowest Dry period	48% Oct – Sep	46% Nov-Dec Feb-Mar	45% Mar	39% Apr	32% Feb
	The highest wet period	52% Oct – Sep	54% Nov-Dec	55% Mar	61% Apr	68% Feb, 59% Oct
	The lowest wet period	3% July	10% August	7% July	7% July	3% July
3 Monthly	The highest Dry period	54% SPI3-3 Apr	61% SPI3-3 Apr	55% SPI 3-2 Jan	54% SPI 3-2 Jan	59% SPI3-4 July
	The lowest Dry period	46% SPI3-4 July	46% SPI3-4 July	48% SPI 3-1 Oct	46% SPI 3-1 Oct	43% SPI3-2 Jan
6 Monthly	Dryness	50% SPI6-1 Oct	46% SPI6-1 Oct	52% SPI6-1 Oct	46% SPI6-1 Oct	52% SPI6-1 Oct
	Dry	46% SPI 6-2 Apr	45% SPI 6-2 Apr	55% SPI 6-2 Apr	52% SPI 6-2 Apr	52% SPI6-2 Apr
12 Month	Dryness	54%	46%	52%	52%	55%

Table 4.2. (Continued).

		Zuara	Tripoli Airport	Nalut	Misurata	Sirt
Monthly	The highest Dry	Dec. (2000-2001)	July (2005-2006)	Dec. (2000-2001)	March (1999-2000)	Feb (1984-1985)
	The highest Moist	July (1985-1986)	August (2004-2005)	July (1988-1989)	July (1995-1996)	July (2005-2006)
3 Monthly	The highest Dry	SPI3-3 Apr. (1988-1989)	SPI3-2 Jan. (2008-2009)	SPI3-1 Oct. (1982-1983)	SPI3-3 Apr. (1998-1999)	SPI3-2 Jan. (2008-2009)
	The highest Moist	SPI3-1 Oct. (1984-1985)	SPI3-4 July (1996-1997)	SPI3-1 Oct. (1995-1996)	SPI3-2 Jan. (1994-1995)	SPI3-4 July (1985-1986)
6 Monthly	The highest Dry	SPI6-1 Oct (.2000-2001) Extremely Dry	SPI6-2 Apr. (1998-1999) Exceptionally Dry	SPI6-2 Apr. (1983-1984) Exceptionally Dry	SPI6-1 Oct. (1993-1994) Extremely Dry	SPI6-1 Oct. (2000-2001) Exceptionally Dry
	The highest Moist	SPI6-1 Oct. (1984-1985) Exceptionally Moist	SPI6-1 Oct. (1980-1981) Exceptionally Moist	SPI6-1 Oct. (1995-1996) Exceptionally Moist	SPI6-1 Oct. (1980-1981) Exceptionally Moist	SPI6-2 Apr. (1985-1986) Exceptionally Moist
12 Month	The highest Dry	SPI -12 (2000-2001) Exceptionally Dry	SPI-12 (2000-2001) Exceptionally Dry	SPI-12 (1992-1993) Exceptionally Dry	SPI-12 (2000-2001) Extremely Dry	SPI-12 (2000-2001) Exceptionally Dry
	The highest Moist	SPI-12 (1984-1985) Exceptionally Moist	SPI-12 (2000-2001) Exceptionally Moist	SPI-12 (1995-1996) Exceptionally Moist	SPI-12 (1980-1981) Exceptionally Moist	SPI-12 (1980-1981) Extremely Moist

Table 4.3. The abstract of RDI results of all stations.

		Zuara	Tripoli Airport	Nalut	Misurata	Sirt
Monthly	The highest Dry	November (2000-2001)	November (2000-2001)	December (2000-2001)	March (1999-2000)	Feb (1984-1985)
	The highest Moist	August (2005-2006)	August (2004-2005)	July (1988-1989)	July (1995-1996)	July (2005-2006)
3 Monthly	The highest Dry	RDI3-3 Apr (1998-1999) Exceptionally Dry	RDI3-2 Jan (2008-2009) Extremely Dry	RDI3-1 Oct (1981-1982) Exceptionally Dry	RDI3-3 Apr (1998-1999) Extremely Dry	RDI3-2 Jan (2008-2009) Exceptionally Dry
	The highest Moist	RDI3-1 Oct (1984-1985) Exceptionally Moist	RDI3-4 Jul (1996-1997) Exceptionally Moist	RDI3-1 Oct (1995-1996) Exceptionally Moist	RDI3-2 Jan (1994-1995) Exceptionally Moist	RDI3-4 Jul (1985-1986) Exceptionally Moist
6 Monthly	The highest Dry	RDI6-2 Apr (1998-1999) Extremely Dry	RDI6-2 Apr (1998-1999) Exceptionally Dry	RDI6-2 Apr (1983-1984) Exceptionally Dry	RDI6-1 Oct (1993-1994) Exceptionally Dry	RDI6-1 Oct (2000-2001) Exceptionally Dry
	The highest Moist	RDI6-1 Oct (1984-1985) Exceptionally Moist	RDI6-1 Oct (1980-1981) Exceptionally Moist	RDI6-1 Oct (1995-1996) Exceptionally Moist	RDI6-1 Oct (1980-1981) Exceptionally Moist	RDI6-2 Apr (1985-1986) Exceptionally Moist
12 Month	The highest Dry	RDI-12 (2000-2001) Exceptionally Dry	RDI-12 (2000-2001) Exceptionally Dry	RDI-12 1992-1993) Exceptionally Dry	RDI-12 (2000-2001) Exceptionally Dry	RDI-12 (2000-2001) Exceptionally Dry
	The highest Moist	RDI-12 (1984-1985 Exceptionally Moist	RDI-12 (1980-1981 Exceptionally Moist	RDI-12 (1995-1996 Exceptionally Moist	RDI-12 (1980-1981 Exceptionally Moist	RDI-12 (1980-1981 Exceptionally Moist

PART 5

CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSION

Using sound, clean technology, the Great Man-made River project has little effect on the environment and maximizes socio-economic advantages. The results of hydrogeological studies and ongoing monitoring of the Libyan desert basins' phase one wellfields show that there are huge, high-quality stores of groundwater there that can meet demand for more than a century. The depletion of reservoirs is a gradual process that may be controlled.

Water cost evaluations show that the Great Man-made River project is still the most cost-effective choice when compared to other supply options. To address water shortages in North and Northeast Africa when conventional wellfields close to demand centers are exhausted, this project serves as a paradigm. In the event of transboundary circumstances, international collaboration amongst sharing governments may be required.

The effects of the drought may be broken down into two categories: those that are directly felt by people and those that are felt by the socioeconomic and environmental system as a whole. It is also possible to organize it in a first- or second-order fashion. A decline in food production owing to a reduction in crops and yields is the immediate result of the first batch of drought in agricultural cultures. Indirect and second-order consequences in these areas include a decrease in employment and income due to a decrease in land usage, a decrease in operations (irrigation and harvesting), and a decrease in harvesting. The price of food rises quickly when there is a decrease in food output due to drought. The prevalence of such issues, particularly for small farmers and landless laborers, is obvious. Declining food output leads unnaturally to increasing food costs, and lack of access to suitable occupations lowers rural people's access to food. When there is a severe drought, unpleasant and unconventional uses of water resources, as well as poor water distribution networks, worsen the situation.

Within the scope of this thesis, the SPI and RDI values were calculated for 1-, 3-, 6-, and 12- months using the Precipitation Drought Index method and the Reconnaissance Drought Index method for 5 monitoring stations in the Great Man-Made River area. Many methods assessed drought and its development in various factors. Therefore, according to methods, developed by Palmer (1965) [3] to translate drought into the language of mathematics and Palmer Drought Severity Index (PDSI) based on precipitation and temperature data [4], and had analyzed solely of precipitation data Standardized Precipitation Index (SPI) which had explored meteorological drought [5]. Therefore, Reconnaissance Drought Index (RDI) had analyzed various methods which are usedduring the completion of the procedure. The results are summarized below:

- First, for the SPI index:

  - ~ In the SPI analysis of all stations on a monthly basis, in Zuara station it is found that August is drier than other months with 79% ratio and for Tripoli Airport station it was recorded that July was drier with 86%, at Nalut station it is discovered that August was drier than other months with 86%, and for Misurata station August turned out to be drier with 79%, at Sirte station it turned out that June is drier than other months with 76%.
  - ~ In calculating SPI-3 for all stations based on the monthly rainfall data in Zuara station, the highest values of drought are observed in SPI3-3 April in 1988-1989 exceptionally dry, and the highest value of humidity in SPI3-1 October in 1984-1985 exceptionally moist, at Tripoli Airport station the highest value for drought in SPI3-2 January in 2008-2009 extremely dry and the highest value for moisture in SPI3-4 July in 1996-1997 exceptionally moist, at Nalut station the highest value for drought is in SPI3-1 October in 1982-1983 exceptionally dry, and the highest value for moisture in SPI3-1 October In 1995-1996 exceptionally moist. For Misurata station, the highest value of drought is in SPI3-3 in April in 1998-1999 extremely dry, and the

highest value in humidity was in SPI3-2 in January in 1994-1995 exceptionally moist, in Sirte station, the highest value of drought is in SPI3-2 in January in 2008 -2009 exceptionally dry and the highest value of moisture was in SPI3-4 July in 1985-1986 exceptionally moist.

~ In calculating SPI-6 for all stations in Zuara station, the highest value of dryness and humidity is observed in SPI6-1 in October, the highest value of drought in 2000-2001 extremely dry and the highest value of humidity in 84-1985 exceptionally moist; at Tripoli Airport station, the highest value of drought in SPI6-2 April in the year 1998-1999 exceptionally dry, and the highest value of humidity is in the year 1993-1994 exceptionally moist; in Nalut station, the highest value of drought was in SPI6-2 in April in the year 1983-1984 exceptionally dry, and the highest value of humidity is in SPI6-1 in October in the year 1995-1996 exceptionally moist; for the Misurata station the highest value of dryness is observed in SPI6-1 October in the year 1993-1994 and the highest value humidity in the year 1980-1981 as exceptionally moist; in Sirt station the highest value of drought was in SPI6-1 October in the year 2000-2001 exceptionally dry, and the highest value of humidity was in SPI6-2 April in the year 85-1986 exceptionally moist.

~ In calculating SPI-12 for all stations, the maximum value of dryness and humidity in Nalut station was in relation to drought in 1992-1993 exceptionally dry (-2.25), and humidity in 1995-1996 exceptionally moist (2.96).

- Second, for the RDI index:

~ In the monthly RDI analysis for all stations using monthly precipitation data and mean monthly temperatures, it was found that the maximum value of the Reconnaissance drought at Tripoli Airport station in year 2000-2001 is in November month (-2.98), and in the analysis of RDI-3 it is found that the highest value of drought is in Nalut station in RDI3-1 October in year 1981-1982 exceptionally dry, in the analysis of RDI-6, it is found that the highest value of drought is in Sirte station in RDI6-1 October in the year 2000-2001 exceptionally dry, in the analysis of RDI-12, the maximum value of reconnaissance drought is in Zuara station in 2000-2001 year exceptionally dry.

5.2. RECOMMENDATIONS

In general, when 5 monitoring stations from the state meteorological station in the region of The Great Man-Made River is taken into account, it has been determined that the drought index value has decreased in almost all of the periods and stations, that is, the drought has increased. The change process of an important event such as hydrological drought, which causes more economic impact than other types of drought, should be followed over time and necessary technical and social measures should be taken accordingly. Considering that important irrigation works have been carried out using the water resources of basin together with the increasing drought in recent years, it will be beneficial to understand why the water resources in the basin should be used efficiently. For example, wild irrigation should be abandoned and sprinkler irrigation methods should be preferred. In order to take precautions for the future, engineering structures such as underground dams should be built. Plant cultivation, which needs less water, should be given importance.

- To monitor hydrological drought in the region, which is subject to transboundary waters, flow observation station data must be measured on a yearly basis in order to identify the trend of hydrological drought and observation stations in this context.
- To improve the effectiveness and performance of Libyan meteorological stations, work must be done to expand the number of synoptic stations, as well as improvements to data completeness, station standards, and operating protocols, as well as frequent training for operational station meteorologists.
- The statistical tests performed in the study demonstrate that winter and fall rains in coastal sites have reduced during a 29-year timeframe. Given that rainwater is utilized for soil storage and agricultural irrigation during dry seasons, a decrease in winter rainfall may pose problems with agricultural land, which is diminishing over time. As a result, actions should be taken to prevent or mitigate the detrimental effects of climate change on our country, as demonstrated by

poor rainfall and rising temperatures. The formulation and implementation of water resource management plans is the most significant of these measures.

- It is recommended to study the time period from 2009 to 2021 in order to know and measure indicators related to precipitation, temperature, and drought in the areas studied, as well as areas and stations located in cities where the man-made river does not pass through, in order to know the rainfall rate, temperatures, drought rates, and SPI coefficient, as well as potential shortcomings and restrictions (SPEI) related to groundwater.
- More research on climate and hydrology is needed to determine drought and global warming indicators that affect rainfall and temperature data.
- It is recommended that you investigate the stations in Libya's eastern areas, which include Benghazi, Al-Marj, Al-Bayda, Derna, and Tobruk. To study and comprehend rainfall and drought, as well as compute and compare the SPI factor to western locations such as Zuwara, Tripoli, and Misurata. For the cities of Sirte, Ajdabiya, and Benghazi, researchers should perform a study to ascertain the characteristics of drought in successive years for a specific future time period.
- A study should be done to identify the number of drought years over a period of more than 25-30 years, compare them to temperatures at various stations, and monitor the growth in evaporation and transpiration.
- It is recommended that Libyan authorities implement a strategy to increase crop and livestock production to the highest level of self-sufficiency while reducing reliance on imports from foreign markets to the lowest level possible, as well as increasing labor productivity and capital investment in the sector, and producing raw materials for food processing industries.

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RESUME

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