Investigation of meteorological drought characteristics of the great man-made river region: a case study of drought in Libya

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Abstract
Drought is a hidden natural hazard that involves complex climatic systems and has significant environmental and social consequences. Due to the current state of catastrophic climatic occurrences, there has been an increased interest in monitoring droughts in recent years. This study conducted meteorological drought analysis for five monitoring stations in the Great Man-Made River region located in Libya. The Standardized Precipitation Index (SPI) and Reconnaissance Drought Index (RDI) methods were used to determine meteorological droughts utilizing monthly total precipitation data, and mean monthly temperatures and monthly total precipitation data, respectively. The drought analysis of the Great Man-Made River region using DrinC software for 1-, 3-, 6-, and 12-month SPI values were researched. According to the SPI-12-month index values, the driest period was determined by 86% in the Tripoli Airport and Nalut station, and the least dry period was determined in the Sirt station by 39%. It was found that the year 2000–2001 was one of the driest years in all studied stations, and the other years with high drought rates were 1981–1982, 1984–1985, and 1992–1993.

Keywords  Drought analysis · Meteorological characteristics · Standardized Precipitation Index (SPI) · Reconnaissance Drought Index (RDI) · Libya

Introduction
Drought is one of the current natural disasters significantly affecting different regions on small and large scales. Drought creates environmental, economic, and social issues in the affected regions. Among the various disasters known in the world, drought is termed as a natural disaster, although different definitions have been made of the drought (McMahon and Arenas 1982). During drought, a lack of moisture typically causes a severe hydrological imbalance. Due to the aforementioned condition, drinking water is usually lost due to high precipitation, which has profound implications for humans and the earth. Due to water deficiency, the affected areas also suffer from dry weather that causes long-lasting water scarcity. According to Hagman et al. (1984), drought is more common than any other disaster globally. Droughts are the most complex of all-natural disasters that have substantially affected humans, but it is among the least understood nature’s phenomenon (Beran and Rodier 1985). In a specific period and under specific circumstances, the area’s decrease in water availability is termed as drought. Drought has been affecting various regions of the world every year (Hisdal and Tallaksen 2003).

With the emergence of drought as a result of the lack of rainfall, the water, and water resources, which were the source of life, decreased in the Libya region, and accordingly, it might harm agricultural productivity. In this condition, some issues might arise under the phenomena of the agricultural and hydrological drought, which occurred because of Libya’s meteorological drought at a time when Libya suffered a dry period. There are certain agricultural sectors, which is one of Libya’s most essential sectors, that had suffered a downfall due to the agricultural drought. Similarly, the products cultivated by the farmers, considered to be the most basic elements of this sector, are generally dependent on the climate. Therefore, a decrease in rainfall usually causes problems such as a decrease in the yield of...
the products and the inability to meet the country’s food needs (Öztürk 2002).

Considering the severity, duration, and effects of the drought, there are certain drought types, including meteorological, agricultural, hydrological, and socioeconomic droughts (Wilhite and Glantz 1985). Meteorological drought is expressed depending on the degree and duration of drought. Depending on the rainfall data, it is the first type of drought that we come across. It is evaluated in seasonal, water-year, or annual time scales (Sen 2009a, b). Agricultural drought is examined as a result of a shortage of rainfall due to meteorological drought and deterioration of soil water. The water demand of a plant depends on that plant’s biological properties along with the growth or stages of the physical and biological properties of the soil (Wilhite 2000). Hydrological droughts mean a lack of water in the hydrological system. It was a type of drought that manifested itself at unusually low water levels in rivers, lakes, reservoirs, and groundwater. The socioeconomic drought occurred due to linking the supply and demand of economic goods or services with meteorological, hydrological, and agricultural drought factors. Therefore, drought can happen due to increased demand for supply goods and decreased climate factors (e.g., low level of rainfall) (Van Loon 2015).

Due to the current state of catastrophic climatic occurrences, there has been an increase in interest in drought consequences and monitoring in recent years. Drought events have an impact on many of the Global Earth Observation System of Systems (GEOSS) and Societal Benefit Areas (SBAs). Drought has created a link between various fields, including agriculture sustainability, food security, ecosystem functions and services, biodiversity, carbon stocks, water resources, and wildfires, to name a few. According to the IPCC’s 5th Assessment Report, a drop in precipitation, coupled with increasing temperatures associated with drought occurrences, is expected, particularly in the Mediterranean Basin, resulting in lower water availability for natural and agricultural systems and human requirements. Hence, this study aims to determine the longest drought period in the study area. The main concern is finding one of the driest years of all the stations and the years with high drought rates. For the purpose of this study, located in the Great Man-Made River region, meteorological drought analysis will be conducted for five monitoring stations in Northern Libya. It should be noted that drought is highly hazardous in the Mediterranean region for two main reasons: first, the Mediterranean climate is altering more rapidly than the global average, and this is likely to continue, implying that more severe droughts are highly probable. Second, the main component that defines the Mediterranean climate is the mixture of substantial drought as well as the hottest season. As a result, research such as this study can significantly improve our understanding of long-term climate trends in Mediterranean areas. In contrast to other studies that mainly focused on a site-specific region (Cavuş and Aksoy 2019; Soliman (2020); ; Hadri et al. 2021; Derdous et al. 2021), this study discusses and elaborates more comprehensive research spatially and temporally using different methods at the Libya region.

Table 1 Rainfall monitoring stations and their geographic locations

| Station number | Station name | Coordinate and altitudes |
|----------------|--------------|--------------------------|
| 62,007         | Zuara        | 32.53 N 12.05 E 03 m     |
| 62,010         | Tripoli Airport | 32.40 N 13.09 E 81 m   |
| 62,002         | Nalut        | 31.52 N 10.59 E 621 m    |
| 62,016         | Misurata     | 32.19 N 15.03 E 32 m     |
| 62,019         | Sirt         | 31.12 N 16.35 E 13 m     |

Fig. 1 Northern Libya and locations of rainfall monitoring stations by Google Maps and Paek et al. (2021)
drought (Nalbantis 2008). An attempt is made by Aksoy (2018) for the drought analysis with the SPI method using the data of 35 stations in the Gediz Basin with at least 10 years of measurement between 1960 and 2016. Their study utilized SPI values for the periods of 3, 6, and 12 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 (Aksoy et al. 2018). Al-Qinna et al. (2011) used SPI and Normalized Difference Vegetation Index (NVDI) to explore the average day-to-day temperature and metrological drought analysis of the Hashemite Kingdom of Jordan between 1970 and 2005. According to their results based on the drought indices, extreme drought was observed in the period 1999–2000, and it was stated that the country was exposed to drought cycles for the upcoming 35 years. Moreover, Apak (2009) analyzed the drought origins in stations with long-term rainfall measurements in the Aegean region using the SPI method for two periods, 1938–1970 and 1971–2006. Their research concluded 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 compared to the first period. Arslan et al. (2016) investigated the droughts that occurred in the Gediz Basin using the SPI index for 1-, 3-, 6-, 9-, 12-, and 60-month periods using monthly precipitation data of 8 meteorological precipitation stations between 1973 and 2013. Their study showed 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. In addition that, in the study carried out by Soliman (2020) in the North Libya, it was stated that while a decreasing trend was observed in precipitation at many stations, an increasing trend was observed in temperatures using trend analysis.

![Dry/moist period distributions according to the 3-, 6-, and 12-month SPI values in the Zuara station](image)

**Fig. 2** Dry/moist period distributions according to the 3-, 6-, and 12-month SPI values in the Zuara station
Methods

Study area and data description

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 SPI and RDI based on the DrinC software in five meteorological stations using data from 1980 to 2009. Consequently, temporal changes in drought index values were examined through drought analysis. Northern Libya is the study area as rainfall is decreasing near the Libyan coast. The study area is located between the longitudes of 9 and 25 east and 30 and 33 latitudes of the north. It should be noted that the analysis is made through monitoring data from the stations based on the atmospheric droughts using the precipitation index of droughts, as seen in Table 1 and Fig. 1.

Since most of the Libya lands lay in arid regions and barely had any rainfall, which ultimately led to water shortage to farmlands, albeit the availability of agricultural potentials. Hence, the active factor in agriculture production is water and significant factors of lives for plants, soil and human. 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 water caused 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. Consequently, the Man-Made River Project was carried out, 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. 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 (Mosbah 1996). The underwater basins are the source of irrigation for agriculture and fertile land. It is also a source of drinking for the local area people (Murray 1952).
**Al Serir basin**

This basin is extended from the Serir region to the Mediterranean coast. Its waters were latent at a layer of 600 m deep and contained 1000 km³ of water. Therefore, 84% of this water was of good quality and ready for usage (Murra 1952).

**Murzuq basin**

The second main basin is situated in the Fezzan region southwest of Libya, covering an area of 450,000 units and containing 4800 km³ of water. It is famous for its high-quality water and salinity of not more than 300 (ppm) (Abolgma 1995).

**Al Hamada basin**

This basin is in the northern Fezzan region and extends along the Jabel Al-Sawda up to the Mediterranean Sea. Studies confirmed that the waters of the Serir and Hamada basins are of lower quality (Public Authority for Agricultural Production 1989).

**Al Kufra basin**

This basin is located southeast of Jamahiriya. It was the largest of the main underground basins, covering an area of 350,000 km² and containing 3400 km³ water. It should be noted that 90% of this underground reserve capacity is still awaiting exploitation (Public Authority for Agricultural Production 1989).
The DrinC software

The Drought Indices Calculator (DrinC) was created to offer a user-friendly tool for calculating a variety of drought indices. The widest potential applicability for various types of droughts (meteorological, hydrological, agricultural) and varied places was a key goal in its design. Drought studies are also seen to be particularly important in dry and semi-arid regions, where data are typically scarce. As a result, the following are the primary criteria for choosing this software:

1. It has relatively low data requirements, allowing its applications in many regions.
2. Their results can be clearly interpreted for direct and efficient operational use.

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).
- The Stream Flow Drought Index (SDI).
- Standardized Precipitation Index (SPI).
- Precipitation Deciles (PD).

They could be easily understood; RDI, SPI, and PD refer to the meteorological drought and are used as the main determinant of precipitation (Valipour 2017; Farooq et al. 2022). Further, RDI could also be used for the agricultural drought analysis, as it could adequately describe the water balance, and it is particularly useful when reference periods related to the development stages of the crop were selected (Palmer 1965). On the other hand, SDI would be applied to hydrological drought and used stream flow as the key determinant (Tsakiris et al. 2010). 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 three key advantages to the user since it has provided the flexibility

Fig. 5 Temporal distribution of 3-, 6-, 12-month SPI values of the Tripoli station
to select among various options for adjusting the outputs to their particular needs. In addition, there is a short presentation and the key characteristics of the drought indices calculated by DrinC (Tsakiris et al. 2010).

Results and discussions

This research calculates and evaluates the SPI and RDI values for 1, 3, 6 and 12 months. The data used are the values of the monthly total precipitation and monthly mean temperature belonging to five meteorological stations situated in the region of The Great Man-Made River, Libya.

The Zuara station meteorological drought analysis

According to SPI values, the monthly dryness ranged between 48 and 79%. The highest dry period was in August, the lowest dry period was in October/September, and the dry and humid periods were equal in November and December. The period of drought and moisture for each of 3, 6, and 12 months for the SPI values are shown in Fig. 2. The Driest periods with the highest SPI-3 values are SPI3-3 in April at 54%, and the lowest dry period is SPI3-4 in July at 46%. Dryness and moisture are equal in SPI6-1 in October at 50%, SPI6-2 in April. SPI-12 shows dryness at 54%, and moisture at 46%.

According to the values of 1-month SPI obtained from the monthly rainfall data, the presence of the middle dry period was determined in July for long years. While the extremely dry period was experienced in November and
December 2000–2001, the extremely wet period was July 1985–1986. Figure 3 shows the distribution time of SPI values for 3-, 6- and 12-month estimation of SPI values. While SPI-3 for October 1981–1982 shows a severely dry period, the year 1984–1985 experienced an extremely wet period. SPI-3 January for the year 1980–1981 showed an extremely dry period. Moreover, the year 1989–1990 was very wet. When the SPI values were checked for 6 months, SPI-6 October 2000–2001 and SPI-6 April 1998–1999 were found to be severely dry. According to SPI-12 values, the year 2000–2001 was defined as extremely dry, while the year 1984–1985 was extremely wet.

The Tripoli station meteorological drought analysis

Based on the SPI values, the monthly dryness ranged between 46 and 86%. The highest dry period is 86% in July and 76% in June, with the lowest dry at 46% period in December and November. Figures 4 demonstrates the 3-, 6- and 12-month dryness and humidity rates in the Tripoli Station. The dry periods with the highest SPI-3 values are SPI3-3 in April at 61%, and the lowest dry period is SPI3-4 in July at 46%. For the periods SPI6-1 in October and SPI6-2 in April, the dryness was 54% and 55%, respectively. SPI-12 shows dryness at 46%, and moisture at 54%.

The middle dry period was determined in July for long years. While the extremely dry period was seen in November 2000–2001, the extremely wet period was August 2004–2005 (similar to July). Figure 5 illustrates the time distributions of SPI values for 3, 6 and 12 months. The SPI-3 October 2000–2001 experienced a severe dry period, while the year 1980–1981 was an extremely wet. The SPI-3 January year 2008–2009 was severely dry, while the year 1981–1982 was extremely wet. The SPI-3 April 1998–1999 observed a severely dry period, while 1993–1994 was an extremely wet. The SPI-3 July 1981–1982 and 2006–2007 were severely dry, while 1996–1997 were identified as
extremely wet. When the SPI values were checked for 6 months, SPI-6 October year 2000–2001 was severely dry. Moreover, SPI-6 April 1998–1999 was also determined to be severely dry. According to SPI-12 values, the year 2000–2001 was defined as severely dry, while the year 1980–1981 was extremely wet.

The Nalut station meteorological drought analysis

Monthly dryness ranged between 45 and 86% in the Nalut Station. While the highest dry period was 86% in August, the wet period was 55% in March. Figure 6 shows 3-, 6- and 12-month dryness and humidity rates. The driest periods with the highest SPI-3 values were SPI3-2 in January (55%), and the lowest dry period was SPI3-1 in October (48%). For the periods SPI6-1 in October and SPI6-2 in April, the dryness and moisture were 52% and 55%, respectively. Moreover, SPI-12 showed dryness and moisture values at 52% and 48%, respectively.

According to SPI values obtained from the monthly total rainfall data, while the highest dry period was in December 2000–2001, the highest wet period was July 1988–1989. Figure 7 demonstrates the time distributions of SPI values for 3, 6 and 12 months. The SPI-3 January 2004–2005 was extremely dry, while 1995–1996 was extremely wet. The SPI-3 April 1998–1999 observed a severe dry period, while the year 1990–1991 was extremely wet. In addition, SPI-3 July year 2007–2008 was identified as extremely wet. When the SPI values were checked for 6 months, SPI-6 October year 1992–1993 and SPI-6 April 1983–1984 were determined to be severely dry. According to SPI-12 values, 1992–1993 was defined as severely dry, while the 1995–1996 was extremely wet.
The Misurata station meteorological drought analysis

The monthly dryness ranged between 39 and 79%. The highest dry period was 79% in August and 71% in June, with the lowest dry period in April (39%). The wet period was the period with high moisture of 61% in April. The periods of dryness and moisture for each of 3, 6, and 12 months are shown in Fig. 8. The driest periods with the highest SPI-3 values were SPI3-2 in January (54%), and the lowest dry period was SPI3-1 in October (46%). For the periods SPI6-1 in October and SPI6-2 in April, the dryness was 46% and 52%, respectively. SPI-12 showed dryness of 52% and moisture of 48%.

According to monthly SPI values, the presence of middle dry was determined in the month of July and August for long years. While the highest dry/extremely dry period was in March 1999–2000, the highest/extremely wet period was July 1995–1996. Figure 9 shows the time distributions of SPI values for 3, 6, and 12 months. The SPI values for 3 months show SPI-3 October 1989–1990 and 1992–1993 as severely dry, while 1986–1987 was extremely wet. While the severely dry period was seen in 1984–1985, the extremely wet period was seen in the 1994–1995 year. In addition, the severely dry periods were seen in the years 1998–1999 and 1980–1981 in SPI-3 April and SPI-3 July, respectively. When the SPI values were checked for 6 months, SPI-6 in October year 1993–1994 was arid. Moreover, SPI-6 April 1982–1983 was also found to be a severely dry. According to SPI-12 values, the year 2000–2001 was defined as severely dry, while the year 1980–1981 was extremely wet.

The Sirt station meteorological drought analysis

According to SPI values, the monthly dryness ranged between 32 and 76%. The driest period was 76% in June and 59% in September, with the lowest in February (32%). The wet periods were the period with high moisture of 68% in February. Figure 10 illustrates the rates of 3-, 6- and 12-month dryness and humidity in the Sirt Station. The driest periods with the highest SPI-3 values were in July (59%), and the lowest dry period was in January (43%). SPI-12 showed dryness of 55% and moisture of 45%.
According to 1-month SPI values, the presence of near-normal period was determined in July and August for long years, while the highest drier periods were in January 2008–2009, November 1980–1981, and 2000–2001, and the highest wet period was July 2005–2006. Figure 11 illustrates the time distributions of SPI values for 3, 6, and 12 months. The SPI values for 3 months show SPI-3 October 2000–2001 as an extremely dry period, while 1991–1992 was a highly wet period. The SPI-3 January 2008–2009 experienced an extremely dry period, while the years 1980–1981 and 1992–1993 were severely wet. The SPI-3 April years 1983–1984 and 1999–2000 were severely dry, while the year 1990–1991 was extremely wet. The SPI-3 July 1980–1981 observed a moderately dry period, while 1985–1986 was identified as an extremely wet. When the SPI values were checked for 6 months, SPI-6 October year 2000–2001 was found to be extremely dry. In addition, SPI-6 April 1980–1981 was found to be severely dry. According to SPI-12 values, the year 2000–2001 was defined as extremely dry, while the year 1980–1981 was extremely wet.

As seen in Table 2, the highest monthly dry periods in all five stations were in the summer months of June, July, and August. Although the Sirt station’s driest month was in September, that was not the case in other stations of Zuara, Tripoli, Nalut, and Misurata. The SPI values for 3 months showed different results for the highest dry period. In the Zuara and Tripoli stations, the dries period was SPI3-3 April, while SPI-3–2 January was the driest period for stations of Nalut, and Misurata. On the other hand, the Sirt station had the driest period in SPI3-4 July.

This inconsistency can be attributed as their different climates in the described stations. In other words, spatial variability can play a significant role in the driest period in a region. As such, due to different climate in studied
stations, more diverse drought results were seen. This shows the significant importance of spatial variability in drought analysis. The 6-month data shows consistent SPI6-1 October as the driest period in all five stations. Moreover, dryness was 55%, 54%, 52%, 52%, and 46% in the Sirt, Zuara, Nalut, Misurata, and Tripoli, respectively. In addition, the SPI results illustrated that the driest periods were mostly between 2000 and 2001 and after 2000s.

As seen in Table 3, similar to SPI index results, the RDI index demonstrated that the driest periods mainly were between 2000 and 2001 and after 2000s. In other words, the SPI and RDI were consistent with the highest dry seasons in all five stations of the Sirt, Zuara, Tripoli, Nalut, and Misurata.

**Conclusion and recommendation**

Drought is a natural phenomenon with severe consequences. Economic, environmental, and societal effects are all significantly affected by severe droughts. With the current drought occurrence rate in Libya due to the lack of rainfall, the region’s water, and water resources, which were the source of life, declined, and it's probable that agricultural productivity will suffer significantly. In this case, various issues could arise due to the agricultural and hydrological droughts that resulted from Libya's meteorological drought. As such, this paper conducted meteorological drought analysis for five monitoring stations in Northern Libya located in the Great Man-Made River region.

The SPI and RDI methods were used to determine meteorological droughts using monthly total precipitation data and mean monthly temperatures. Based on the results, the driest time was defined by 86% in the Tripoli Airport and Nalut stations, and the least dry period was found to be in the Sirt station (76%), according to SPI-monthly index data. In the monthly SPI analysis of all stations, in the Zuara station was found that August is driest with a value of 79%. In Tripoli Airport station, it was recorded that July was the driest at a value of 86%. In the Nalut station, it was discovered that August was the driest at a value of 86%,
### Table 2: The abstract of SPI results of all stations

| Monthly       | Zuara            | Tripoli Airport | Nalut           | Misurata         | Sirt           |
|---------------|------------------|-----------------|-----------------|------------------|----------------|
| 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% SPI3-2 Jan | 54% SPI3-2 Jan | 59% SPI3-4 July |
| The lowest dry period  | 46% SPI3-4 July  | 46% SPI3-4 July | 48% SPI3-1 Oct  | 46% SPI3-1 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% SPI6-2 Apr   | 45% SPI6-2 Apr  | 55% SPI6-2 Apr  | 52% SPI6-2 Apr  | 52% SPI6-2 Apr |
| 12 Month Dryness    | 54%              | 46%             | 52%             | 52%              | 55%            |
| Monthly The highest dry period | December (2000–2001) | July (2005–2006) | March (1999–2000) | July (1995–1996) | Feb (1984–1985) |
| The highest moist period  | July (1985–1986) | August (2004–2005) | July (1995–1996) | July (2005–2006) | July (2005–2006) |
| 3 Monthly The highest dry period | SPI3-3 Apr (1988–1989) | SPI3-2 Jan (2008–2009) | SPI3-3 Apr (1982–1983) | SPI3-2 Jan (1998–1999) | SPI3-4 July (2008–2009) |
| The highest moist period  | SPI3-1 Oct (1984–1985) | SPI3-4 Jul (1996–1997) | SPI3-1 Oct (1995–1996) | SPI3-2 Jan (1994–1995) | SPI3-4 July (1985–1986) |
| 6 Monthly The highest dry period | SPI6-1 Oct (2000–2001) | SPI6-2 Apr (1998–1999) | SPI6-2 Apr (1983–1984) | SPI6-1 Oct (1993–1994) | SPI6-1 Oct (2000–2001) |
| The highest moist period  | SPI6-1 Oct (1984–1985) | SPI6-1 Oct (1980–1981) | SPI6-1 Oct (1995–1996) | SPI6-1 Oct (1980–1981) | SPI6-2 Apr (1985–1986) |
| 12 Month The highest dry period | SPI-12 (2000–2001) | SPI-12 (2000–2001) | SPI-12 (1992–1993) | SPI-12 (2000–2001) | SPI-12 (2000–2001) |
| The highest moist period  | SPI-12 (1984–1985) | SPI-12 (2000–2001) | SPI-12 (1995–1996) | SPI-12 (1980–1981) | SPI-12 (1980–1981) |

### Table 3: The abstract of RDI results of all stations

| Monthly       | Zuara            | Tripoli Airport | Nalut           | Misurata         | Sirt           |
|---------------|------------------|-----------------|-----------------|------------------|----------------|
| Monthly The highest dry period | November (2000–2001) | November (2000–2001) | December (2000–2001) | March (1999–2000) | Feb (1984–1985) |
| The highest moist period  | August (2005–2006) | August (2004–2005) | July (1988–1989) | July (1995–1996) | July (2005–2006) |
| 3 Monthly The highest dry period | RD1-3 Apr (1998–1999) | RD1-3-2 Jan (2008–2009) | RD1-3-1 Oct (1981–1982) | RD1-3-3 Apr (1998–1999) | RD1-3-2 Jan (2008–2009) |
| The highest moist period  | RD1-3-1 Oct (1984–1985) | RD1-3-4 Jul (1996–1997) | RD1-3-1 Oct (1995–1996) | RD1-3-2 Jan (1994–1995) | RD1-3-4 Jul (1985–1986) |
| 6 Monthly The highest dry period | RD1-6-2 Apr (1998–1999) | RD1-6-2 Apr (1998–1999) | RD1-6-2 Apr (1983–1984) | RD1-6-1 Oct (1993–1994) | RD1-6-1 Oct (2000–2001) |
| The highest moist period  | RD1-6-1 Oct (1984–1985) | RD1-6-1 Oct (1980–1981) | RD1-6-1 Oct (1995–1996) | RD1-6-1 Oct (1980–1981) | RD1-6-2 Apr (1985–1986) |
| 12 Month The highest dry period | RDI-12 (2000–2001) | RDI-12 (2000–2001) | RDI-12 (1992–1993) | RDI-12 (2000–2001) | RDI-12 (2000–2001) |
| The highest moist period  | RDI-12 (1984–1985) | RDI-12 (1980–1981) | RDI-12 (1995–1996) | RDI-12 (1980–1981) | RDI-12 (1980–1981) |
while in the Misurata station, August turned out to be the driest at a value of 79%. In Sirt station, it was revealed that June was the driest month, with a value of 76%.

This study showed that during the long years, rains decreased generally in all seasons in coastal stations. Dry periods have been observed in all seasons at different time scales, and 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. Considering that rain waters are used for storage in soil and agricultural irrigation in dry seasons, the decrease in winter rainfall can cause issues in terms of agricultural productivity in the long term. Therefore, some measures must be taken to eliminate or reduce the negative impacts of climate change in Libya, as seen by the low rainfall and increased temperature. The most important of these measures is establishing and implementing new and urgent national water resource management plans.

The change process of an important event such as hydrological drought, which causes more economic impact than any other types of droughts, should be followed over time, and necessary technical and social measures must be taken accordingly. Considering that important irrigation works have been carried out using the water resources of the 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 higher importance.

To monitor hydrological drought in the region, flow observation station data must be measured yearly to identify the trend of hydrological drought and observation stations in this context. In addition, 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. 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 related to groundwater. In addition, it is recommended to 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 Zuwarra, Tripoli, and Misurata. For the cities of Sirte, Ajdabiya, and Benghazi, researchers should study the characteristics of drought in successive years for a specific future 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. The significance of the study lies in the fact that it will aid the competent authorities in the prioritizing of sub-regions based on drought risk and therefore in the formulation of appropriate policies to control the possible dangers coming from dry episodes. It should be noted that the Mediterranean area, the biggest of Europe’s semi-enclosed seas, is bounded by 22 nations that have a coastline of 46,000 km. It also houses approximately 480 million people spread across three continents: Africa, Asia, and Europe. As a result, such study on drought conditions in different Mediterranean regions can improve our understanding of past, current, and possible future water scarcity in the area due to droughts. Moreover, such drought analysis can be utilized in different Mediterranean regions spatially and temporally to reach better understanding of if drought is spreading through whole Mediterranean region or not? In other words, similar methodology based on the SPI and RDI indices can be employed in various Mediterranean countries for long-term drought analysis.

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