



Assessing the Spatio-temporal Variability of Meteorological Drought in Jordan

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Abstract

In the last decade, severe drought impacts have been witnessed in Jordan and there is an immense need to develop drought management strategy and policy framework to tackle this problem. This study aimed to investigate the spatio-temporal variability of precipitation based on long-term data using Standardized Precipitation Index (SPI) to assess the trend and intensity of drought in Jordan. In this context, the data of 29 meteorological stations of the last 37 years have been obtained from Jordan Meteorological Department. SPI-3, SPI-6 and SPI-12 have been calculated to assess short- and long-term drought events, and Mann–Kendall and linear regression tests were applied to detect the drought trend in the study region. Drought of varying duration and intensity was detected at each time scale (3-, 6-, and 12-month SPI) as well as at each meteorological station. The SPI results show that Jordan faces an increasing frequency of drought with a probability of occurrence once in every 2 or 3 years. On contrary to this, long-term drought occurs in whole country once in every 15–20 years which have more than 2-year consecutive duration. The Mann–Kendall test result shows significant temporal decrease in the amount of precipitation at all meteorological stations except Madaba. The results of linear regression test indicate significant increase in magnitude of drought with the rate 0.02/annum with a significance of 0.0001 using SPI values. This study concluded that there is an increasing drought trend and the situation will become more severe in future as the amount of rainfall is decreasing gradually in Jordan.

Keywords Drought · SPI · Mann–Kendall · Linear regression · Trend · DrinC software

1 Introduction

Drought is a natural phenomenon that occurs due to consequence of deficient precipitation than long term normally extended for a period of season, year or more in a region that affects the functions of natural environment and affecting the human activities (Sivakumar 2005). Drought represents a temporary dry period in an area in contrast to the perpetual aridity in arid areas. Drought occurs almost in every part of the world, even in humid regions (UNISDR 2001; Vicente-Serrano et al. 2014). Drought is considered as natural hazard that causes large people migration (Gidey et al. 2018). Since nineteenth century, drought has caused

more than 11 million human losses and likewise 2 billion have been affected that accounts more than any other natural hazard (Gopalakrishnan 2013). Drought is the main cause of malnutrition and mortalities as it causes shortage of food and water (Rahman et al. 2018). Drought has direct and indirect socio-economic and environmental impacts (Rahman et al. 2018; FAO 2017). It badly affects the agriculture sector as well as its associated sectors, i.e. forestry and fisheries. It can lead to massive famine, mass migration, natural resource degradation, frail economy, exacerbate social tensions and unrest (Kastopoulou et al. 2017; FAO, 2017; Langat et al. 2017).

The drought event occurs time to time and alters different regions of the world with different levels of intensity. Therefore, the study of drought indicators is helpful to manage and understand the changing trend and their characteristics in terms of severity and duration (Surendran et al. 2017; Van Loon 2015; Deo and Sahin 2015). There is no single indicator or index that may precisely describe the onset and severity of the event (Zambrano et al. 2017; Vicente-Serrano

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et al. 2010a, b). Droughts are classified in four types based on nature of water deficiency, i.e. meteorological, hydrological, agricultural and socio-economic (AMS 2004; Wilhite and Glantz 1985). In this study, meteorological drought has been addressed to assess the situation of drought in Jordan as it is provided based on the commencement of other types of drought.

According to IPCC (2013), the frequency, severity and duration of drought events have increased with the passage of time. Drought is a devastating natural hazard which affects a significant proportion of the world population, particularly those living in semi-arid and arid regions. Climate change is indeed exacerbating drought in most parts of the world, whereas future climate projections suggest widespread spatial extent of drought to become broadly consistent with expected changes in the hydrological cycle under warming condition (Vicente-Serrano et al. 2014; Gonçalves et al. 2014; Evans 2009; Dai 2011). Several indices have been developed to tackle the issue of drought among those are: Percent of Normal (Willeke et al. 1994), Deciles (Gibbs and Maher 1967), Palmer Drought Severity Index (PDSI) (Palmer 1965), Standardized Precipitation Index (SPI) (McKee et al. 1993), Palfai Aridity Index (PAI) (Palfai 1990) and some other indices that have been used in previous research on drought (Deo et al. 2017). The characteristics of the variables used, local climatic conditions, availability of data and validity determine the index to be applied.

Several studies indicated that arid and semi-arid areas in the Middle East are highly profound to the phenomena of climate change and this region is one of the driest regions of the world (Evans 2009; Black 2009). The Middle Eastern countries are subjected to severe recurrent drought that has affected the development of the region in many aspects (Turk et al. 2016; Mahfouz et al. 2016). ACSAD (2011) classified the drought period of 1998–2001 across this region as the worst in the last 50 years, which affected millions of people. It has become a challenging task for Jordan to provide their population a sustainable livelihood in the drought-exposed environment, as the country faces water scarcity issue as well as land degradation and desertification issues. Climate change places additional constraints on its fragile ecosystems and limited water resources. Recent years have witnessed a significant water shortage and have posed worst impacts on the people, economy and natural environment. In the last three decades, drought incidents have resulted severe social crises in Jordan. This issue needs broad attention from the high-level decision-makers, scientific and policy maker's community (UN 2013).

Drought in Jordan is characterized by increasing frequency and severity with time (Hammouri and El-Naqa 2007; Abu et al. 2015). The frequency of drought events has almost doubled during 1961–2012 compared to 1900–1960. The most recent drought during 1998–2000 has disrupted

economic, environmental, and social sectors of the country. It has affected 40% of red meat and milk production of the country as 30% of sheep flocks either died or slaughtered due to drought. At least 70% of camel herd died due to the effects of 1958–1962 drought period (MoEnv 2014).

Drought occurrence cannot be fully overcome but its consequences can be lessened and the event can be forecasted in the current Era of technological innovations. Likewise, with appropriate policy instruments the impacts of drought can be substantially mitigated. Experiences show that proactive risk-based management approaches are effective in enhancing the resilience of communities and their capacity to cope with such disasters. Despite the progress in technology, prior management and planning is often ignored. The increasing drought trend and future climatic predictions intimate that there is a dire need of planning to overcome the issue of water scarcity for future sustainable development (Törnros and Menzel 2014). The main aim of this study is to investigate the spatial and temporal drought trends through SPI and Mann–Kendall test using temporal precipitation records and to provide a baseline for drought management.

2 The Study Area

Jordan is one of the Middle Eastern developing countries situated in the east of the Mediterranean Sea in a distance of 80 km, between 29°11' and 33°22' north latitude and 34°19' to 39°18' east longitude. Unluckily, the country lacks the natural resource wealth and being ranked among the top water deficit countries in the world, where the water resources are less than 100 L per capita per day (MWI 2015). In addition, the country is facing far behind in agriculture development and faces food insecurity that is because of existing water stress to satisfy the needs for population growth, economic development, and influx of refugees from neighboring countries. These pressures will be significantly exacerbated by the devastating impacts of climate change. Jordan experiencing various micro-climatic conditions due to high altitudinal variability that ranges from –400 m (Dead Sea) to 1750 m above mean sea level at the southern highlands. Thus, the climate varies from dry sub-humid Mediterranean type in the north-west of the country to desert conditions at the majority of the eastern part. In this regard, Jordan is divided into three physiographic regions; highlands receives high amount of rainfall and sometimes snowfall and Jordan Rift Valley is the second physiographic division located in the west of the highlands and it also receives ample amount of precipitation. The land of this physiographic division is fertile and thus mainly used for agricultural purposes. The third region, which represent a large part of desert, has occupied about 90% of total area of

the country and distributed in the northern, central, and eastern parts (Fig. 1).

3 Methods and Materials

3.1 Data Collection and Analysis

Monthly rainfall data for 29 meteorological stations covering the whole country were obtained for the last 37 years from Jordan Meteorological Department (JMD). The characteristics of the long-term historical mean annual rainfall data for all meteorological stations is presented in Table 1.

To characterize and search for monthly rainfall extremes, preliminary statistical analysis was performed for each meteorological station using distribution platform within JMP statistical software (JMP 2011). The preliminary statistical analyses included measure of central tendency (mean, and median), dispersion (standard deviation, coefficient of variation), and distribution (skewness and kurtosis). To determine for evidence of specific rainfall trends, monthly and annual rainfall data were investigated using both Mann–Kendall test and linear regression analysis (time-series linear regression). In linear regression analysis, the coefficient of determination (R^2), root mean square error, and p value as obtained from analysis of variance (ANOVA) are used to determine the significance of the linear trend. Trends are described in a linear equation where both intercept and slope have significant meanings (JMP 2011).

The Mann–Kendall test is a non-parametric statistical test used for indicating trends in time-series data (Paulin and Xiaogang 2005; Kendall 1975; Mann 1945). The acceptance and rejection of the null hypothesis (H_0 : there exists a trend in the data) at certain probability level (α) is based on calculation of Kendall's tau (τ) that measures the association between two ordinal variables (Yue et al. 2002).

3.2 Standardized Precipitation Index (SPI)

Drought indices calculator (DrinC) version 1.5.73 was used as a tool for the calculation of meteorological Standardized Precipitation Index (SPI) (Tigkas et al. 2015). SPI is considered as one of the best for drought studies as it just required precipitation data and have good results to detect drought events in any region. Prior the calculation of SPI, the long-term monthly rainfall data were initially normalized using gamma distribution function along DrinC software. The SPI has been calculated following McKee et al. (1993) methodology through which the value of standardized precipitation is derived by dividing the difference between the average seasonal precipitation and its long-term seasonal precipitation average by its standard deviation:

$$\text{SPI} = \frac{x_{ij} - x_{im}}{\sigma}, \quad (1)$$

where X_{ij} is the seasonal–monthly precipitation at i th rain-gauge station and j th observation, X_{im} the long-term precipitation average and σ is its standard deviation.

McKee et al. (1993, 1995) stated that a drought event occurs when the SPI values are continuously negative and the SPI value intensity reaches to -1.0 or less while the drought event came to its end when the SPI values became positive. Drought severity classified into seven classes in this study; $\text{SPI} > 2$ represents extremely wet conditions, very wet conditions prevail when SPI ranges from 1.5 to 1.99 , while 1.0 – 1.49 indicates moderately wet, near normal -0.99 – 0.99 , moderate drought from -1.49 to -1 , severe drought from -1.99 to -1.5 , and extreme drought $\text{SPI} < -2$.

In this study, SPI values are calculated for annual (SPI_{12}), 6-month (SPI_6), and 3-month bases (SPI_3). The SPI_6 values are classified as SPI_{3W} for the wet period from October to March, and SPI_{3D} for the dry period from April to September. Similarly, the SPI_3 has been classified as SPI_{3JFM} (January–March), SPI_{3AMJ} (April–June), SPI_{3JAS} (July–September) and SPI_{3OCD} (October–December). At each level, drought event is characterized according to the duration and intensity for each month that the event continues.

3.3 Spatial Investigation

To investigate the spatial extent of drought in Jordan, the SPI values of the 29 meteorological stations for the period of 1980–2017 were interpolated using Kriging interpolation technique. The Kriging investigation was performed in four steps (Selker et al. 1999). The first step involved the determination of the types of distribution. The second step dealt with the characterization of spatial distribution that involved computation of semi-variance clouds in all directions using the following equation and tested for isotropy (Selker et al. 1999).

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [(Z(x) - Z(x+h))^2], \quad (2)$$

where $\gamma(h)$ is the semi-variance, $Z(x)$ the regionalized variable, and $N(h)$ the number of pairs of sample data taken a distance h .

The third step is characterized by intricately modeling the choice and construction of best empirical fit to represent the actual SPI spatial variability (Selker et al. 1999). There are different theoretical semi-variogram models that exist, i.e. linear, spherical, Gaussian, exponential, etc., in which the selection is based on both cross-validation test and smallest nugget value. In this step, the final variogram model consists

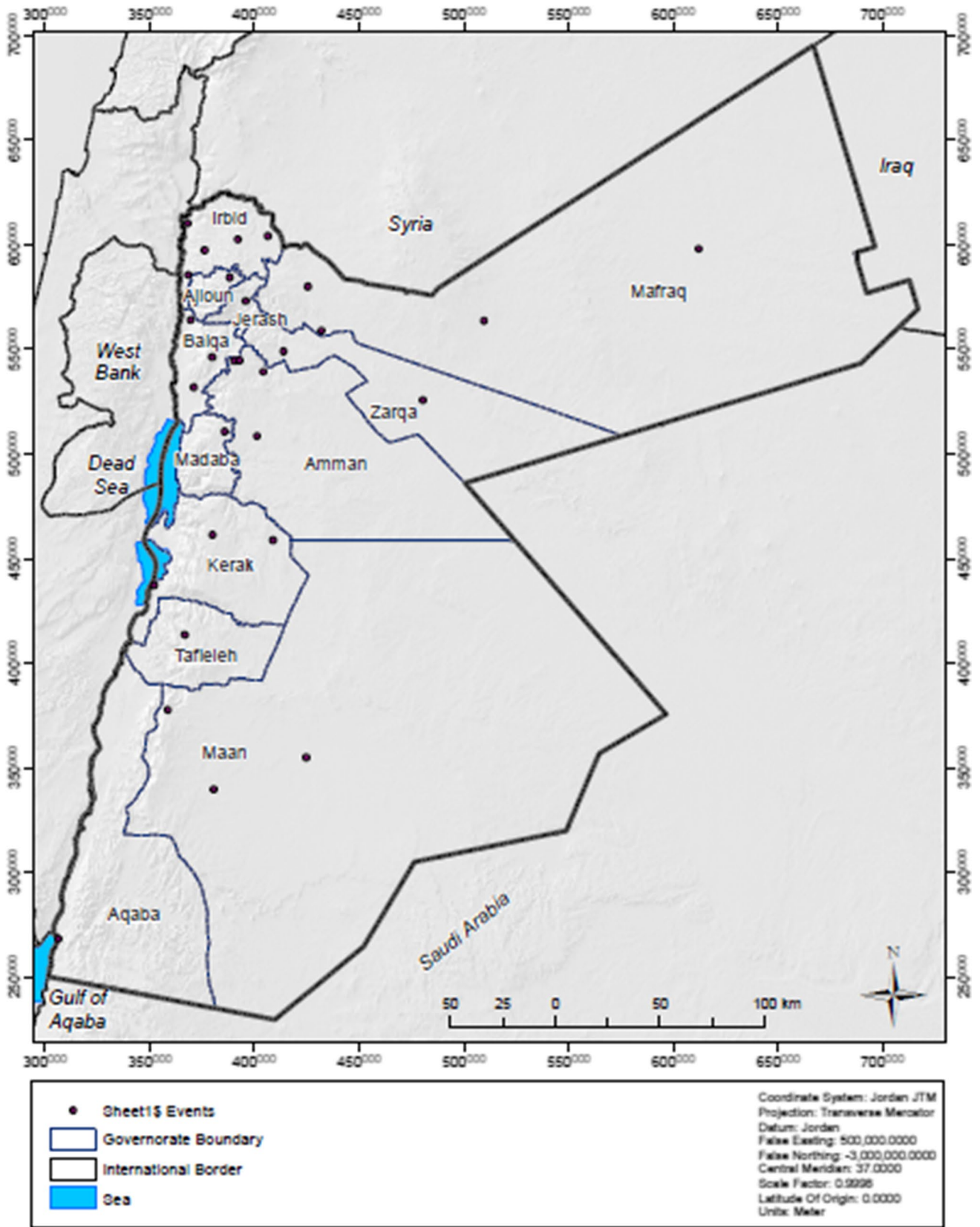


Fig. 1 Hashemite Kingdom of Jordan as a study area

Table 1 Statistical summary for annual rainfall data per station

No.	Station name	Altitude (m)	Mean (mm)	SD (mm)	Min (mm)	Max (mm)	CV (%)	Skewness	Kurtosis
1	Baqura	- 170	392.4	133.3	174.3	918.3	34.0	1.86	5.76
2	DeirAlla	330	282.3	93.1	117.0	599.0	33.0	1.30	2.73
3	Ghor Safi	- 350	72.4	28.6	18.3	151.8	39.5	0.30	0.21
4	Irbid	616	459.6	144.6	216.8	912.9	31.5	1.52	3.20
5	Rabba	920	337.3	103.3	138.0	606.0	30.6	0.39	0.65
6	Shoubek	1365	251.6	97.4	95.0	482.0	38.7	0.72	0.23
7	Tafieleh	1200	203.8	61.5	85.0	358.0	30.2	0.68	0.26
8	Salt	796	550.1	166.8	246.0	1130.	30.3	1.40	3.25
9	Aqaba	51	25.6	21.4	1.0	86.0	83.7	1.05	0.38
10	RasMunief	1150	463.9	142.9	217.0	913.0	30.8	1.50	3.29
11	Amman Airport	790	254.2	88.2	111.0	548.0	34.7	1.67	3.60
12	Mafreq	686	154.8	54.3	65.0	301.0	35.1	0.93	0.98
13	Safawi H5	674	70.1	32.0	16.0	158.0	45.6	0.70	0.53
14	Queen AIA	722	155.9	51.7	56.0	326.0	33.2	1.05	2.68
15	Maan	1069	41.2	24.5	12.0	108.0	59.5	1.17	1.29
16	Al-Jafer	865	31.4	25.7	1.0	135.0	82.0	2.09	6.14
17	Zarqa	664	129.5	45.3	48.0	258.0	34.9	1.14	1.68
18	WadiDhuleil	575	141.0	49.3	54.5	276.0	35.0	1.04	0.94
19	Qatraneh	730	97.3	31.1	25.0	156.0	31.9	- 0.25	0.56
20	Azraq South	610	54.0	30.5	9.0	149.0	56.5	0.90	0.93
21	Reweished H4	683	81.2	36.7	16.0	168.0	45.3	0.09	0.14
22	WadiErRayyan	- 200	308.5	107.0	132.0	708.0	34.7	1.65	4.39
23	Sweileh	1050	468.6	180.1	212.6	1258.3	38.4	2.39	9.23
24	Maddaba	758	307.6	123.1	55.9	755.5	40.0	1.10	3.70
25	Ramtha	590	209.1	90.8	25.9	453.9	43.4	0.63	0.70
26	Dier Abi Said	- 224	461.2	149.1	234.0	942.6	32.3	1.42	3.33
27	South Shuna	- 211	165.5	53.7	57.9	341.4	32.4	0.88	2.27
28	University of Jordan	992	486.9	161.2	225.3	1150.8	33.1	2.05	6.97
29	Jerash	585	364.5	115.9	189.5	696.7	31.8	1.10	1.37

of its three major components; one is distance of independency which means major and minor ranges of the values, second is sill that denotes the ordinary sample variance, and the third step is the nugget representing the measurement error due to micro-regionalization.

In the fourth step, prediction maps are generated for SPI values for unknown locations using Kriging interpolation technique that is also known as Ordinary Kriging technique (Selker et al. 1999). It assumes a constant unknown mean, where the value at the un-sampled point can be predicted by a linear weighting of the variation amongst the neighborhood points derived from variogram analyses from the following equation:

$$Z(X_0) = \mu + \varepsilon(X_0), \quad (3a)$$

$$Z(X_0) = \sum \lambda_i \gamma(x_i), \quad \sum \lambda_i = 1, \quad (3b)$$

where μ is an unknown constant and $\varepsilon(X_0)$ is the error associated with unknown location X_0 , $Z(X_0)$ is the estimated value of Z at X_0 , and λ_i is the weight that gives the best possible estimation from the surrounding points.

3.4 Cluster Investigation

To explore the spatio-temporal patterns of drought at the country, two methods were used: temporal analysis using multi-linear regression and clustering technique. At the multi-linear regression analysis, both time and location were included as independent variables to predict the SPI-12 as a response. The significant effect of each independent variable was estimated from the parameter test using both ANOVA and t-test.

To group the spatial drought pattern based on the SPI data, the hierarchical clusters using Ward's method that joins clusters to maximize the probability at each level of the hierarchy under the assumptions of multivariate normal

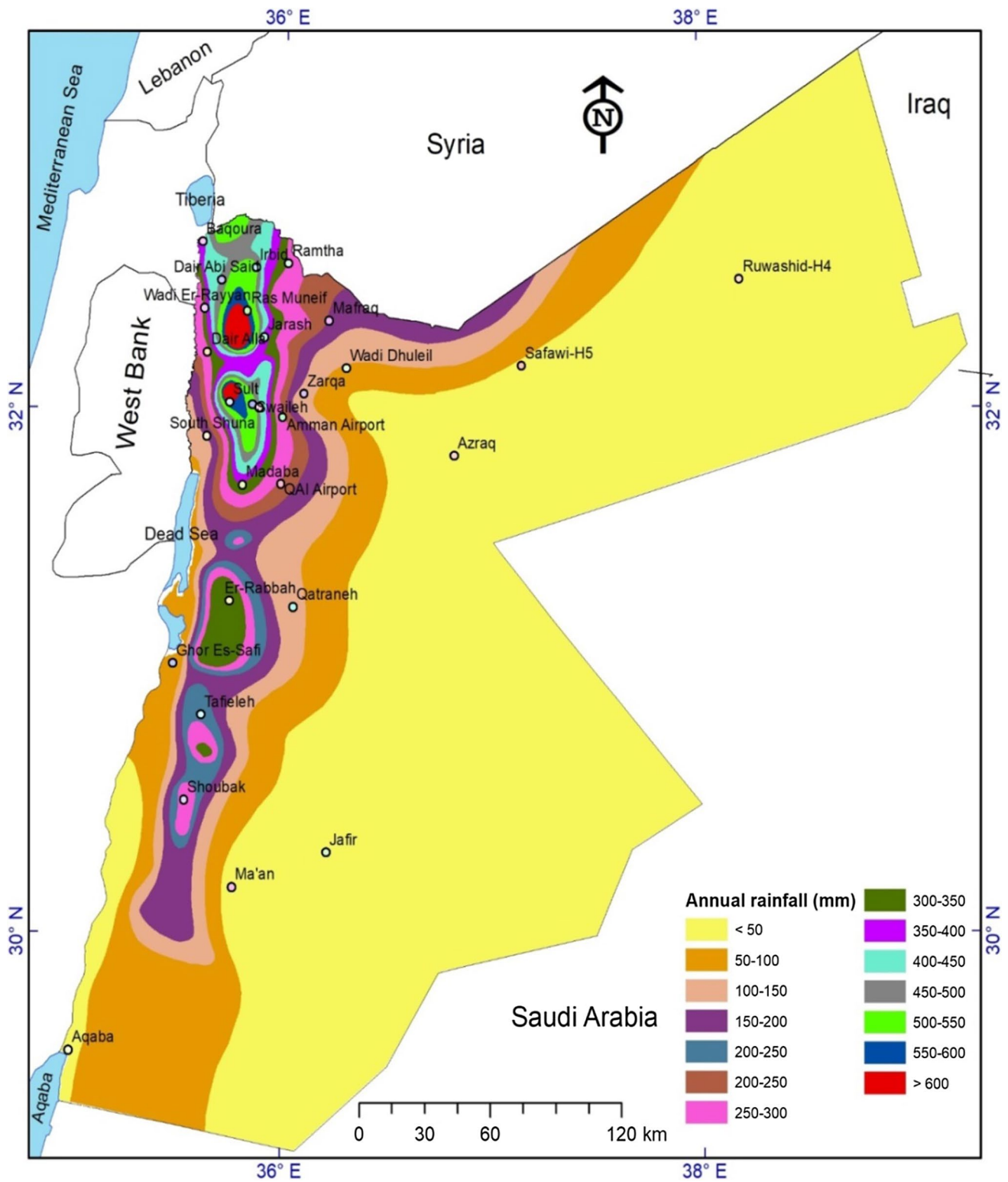


Fig. 2 Rainfall distribution map of the country based on long historical rainfall records. Modified after (MWI 2010)

mixtures, spherical covariance matrices, and equal sampling likelihoods. The clustering was achieved using JMP statistical software.

“In Ward’s minimum variance method, the distance between two clusters is the ANOVA sum of squares between the two clusters added up over all the variables” (JMP 2011).

Table 2 Mann–Kendall test and linear regression trend results for the annual rainfall records per weather station

Station	<i>R</i>	Kendall τ	Prob > τ	Linear trend equation	<i>R</i> ²	RMSE	Prob > <i>F</i>
Baqura	− 0.2310	− 0.1465	0.1954	5796.86−2.71*Year	0.0508	131.7	0.1735
DeirAlla	− 0.2736	− 0.1755	0.1219	4751.47−2.24*Year	0.0714	90.9	0.1049
Ghor Safi	− 0.2238	− 0.2037	0.0722	1195.83−0.56*Year	0.0477	28.3	0.1877
Irbid	− 0.2703	− 0.1835	0.1049	7320.20−3.43*Year	0.0696	141.4	0.1094
ErRabeh	− 0.3352	− 0.1967	0.0827	6420.43−3.05*Year	0.1073	99.0	0.0447*
Shoubek	− 0.4253	− 0.2971	0.0078*	7509.17−3.63*Year	0.1809	89.3	0.0070*
Tafieleh	− 0.3858	− 0.2110	0.0627	4377.6−2.1*Year	0.1425	57.7	0.0195*
Salt	− 0.3131	− 0.1781	0.116	9721.26−4.59*Year	0.0936	161.0	0.0618
Aqaba	− 0.1643	− 0.1304	0.2522	642.62−0.31*Year	0.0257	21.4	0.3365
RasMunief	− 0.2225	− 0.1241	0.2739	6041.09−2.79*Year	0.0471	141.4	0.1904
Amman Airport	− 0.3420	− 0.2071	0.0682	5553.58−2.65*Year	0.1118	84.2	0.0402*
Mafreq	− 0.4197	− 0.2382	0.0357*	4164.22−2.01*Year	0.1688	50.2	0.0104*
Safawi H5	− 0.1836	− 0.1489	0.1907	1099.41−0.52*Year	0.0321	31.9	0.2820
Queen AIA	− 0.3075	− 0.2233	0.0496*	2949.49−1.40*Year	0.0902	50.0	0.0669
Maan	− 0.1496	− 0.0559	0.6236	684.24−0.32*Year	0.0213	24.6	0.3820
Al-Jafer	− 0.2165	− 0.1275	0.2628	1008.17−0.49*Year	0.0446	25.5	0.2029
Zarka	− 0.2834	− 0.0927	0.4137	2380.98−1.13*Year	0.0766	44.1	0.0925
WadiDhuleil	− 0.4176	− 0.2578	0.0229*	3766.28−1.81*Year	0.1672	45.6	0.0108*
Qatraneh	0.0033	− 0.0200	0.8602	79.15+0.01*Year	0.0000	31.5	0.9846
Azraq South	− 0.1530	− 0.1465	0.1954	871.78−0.41*Year	0.0223	30.6	0.3712
Reweished H4	− 0.2208	− 0.0842	0.4581	1504.29−0.71*Year	0.0464	36.4	0.1938
WadiErRayyan	− 0.1876	− 0.1197	0.2908	3826.12−1.76*Year	0.0335	106.6	0.2715
Sweileh	− 0.3278	− 0.2221	0.0498*	10,838.1−5.2*Year	0.1026	173.0	0.0499*
Maddaba	0.0681	0.0640	0.5716	− 1160.45+0.73*Year	0.0044	124.5	0.6922
Ramtha	− 0.4639	− 0.3144	0.0055*	7625.99−3.71*Year	0.2067	82.0	0.0041*
Dier Abi Said	− 0.0032	0.0667	0.5673	544.71−0.04*Year	0.0000	151.3	0.9863
South Shuna	− 0.1147	− 0.0382	0.7437	1244.32−0.54*Year	0.0113	54.2	0.5381
Jerash	− 0.0448	0.0100	0.9299	1274.64−0.46*Year	0.0019	117.4	0.7946
University of Jordan	− 0.2406	− 0.1664	0.1413	7290.79−3.41*Year	0.0552	158.8	0.1558

*Significant at 95% confidence level (probability < 0.05)

At each stage, within-cluster sum of squares is minimized over all partitions attainable by integration of two clusters from the previous stage (Milligan 1980).

4 Results and Discussion

4.1 Spatial and Temporal Analysis of Rainfall

In Jordan, more than half (15 met-stations) of the meteorological stations (Met-Stations) experiencing arid type of climate where average precipitation varies from 25.6 mm in Aqaba followed by 31.4 in Al-Jafer to 209.1 in Ramtha

met-station. The remaining 14 met-stations out of total 29 are experiencing semi-arid type of climate where 251.6 mm rainfall is received in Shoubek and the highest rainfall (550 mm) is received in Salt met-station (Table 1, Fig. 2). The semi-arid conditions prevail in the north-eastern part of the country where elevation is more than 600 m above mean sea level and thus receives more rainfall than the rest of the country. The distribution of rainfall data coincide with rainfall distribution isohyets of the country, where the area representing mean annual rainfalls above 400 mm is only 2% of the country that is located in the north-eastern part of the country. About 90.5% of the country area is characterized

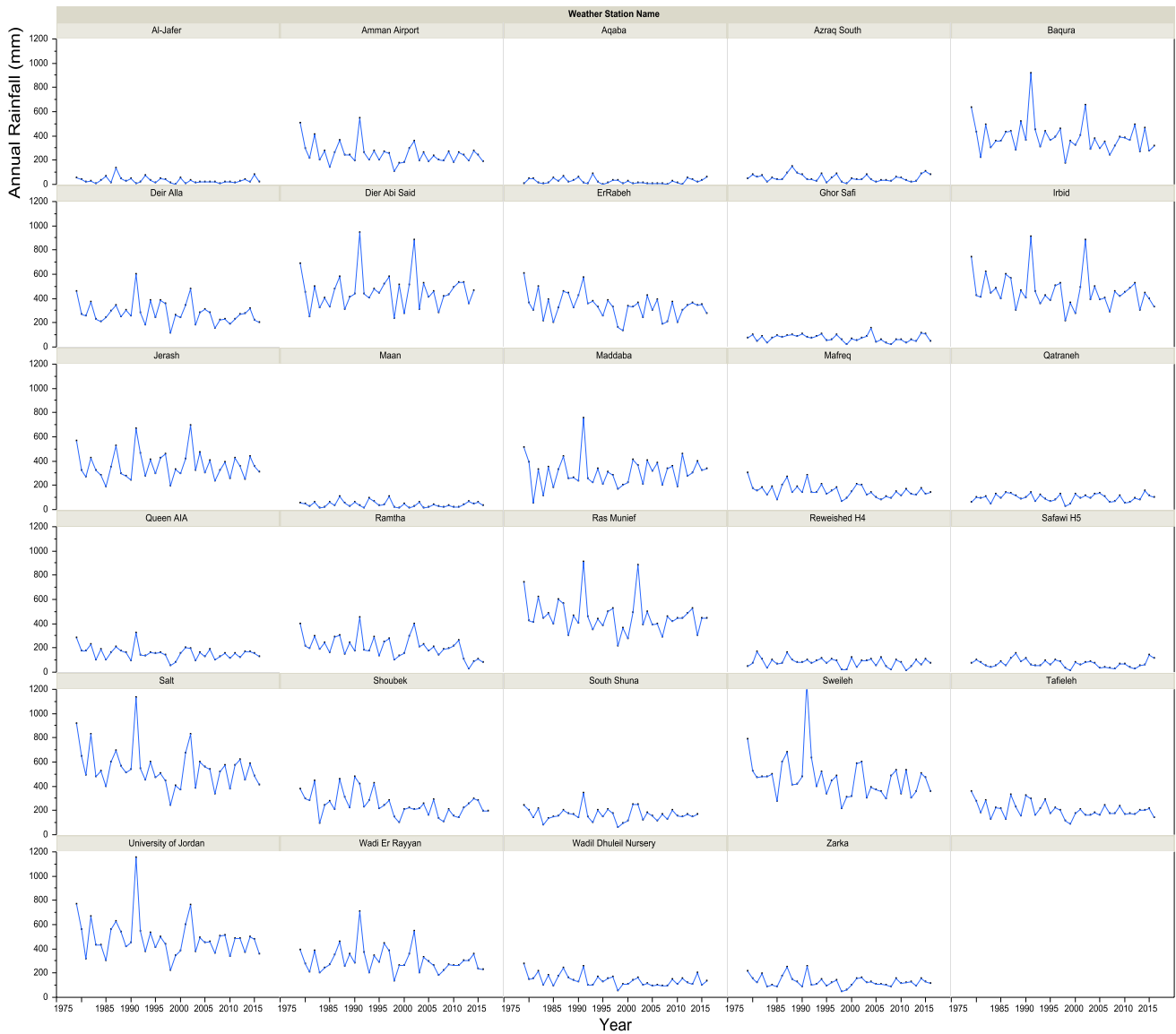


Fig. 3 Historical rainfall distribution by station from 1980 to 2017

Table 3 The observed probability for each category of the annual SPI

Category	SPI class range	Probability (%)						
		SPI ₁₂	SPI _{6W}	SPI _{6D}	SPI _{3JFM}	SPI _{3AMJ}	SPI _{3JAS}	SPI _{3OCD}
Extremely wet	≥ 2.00	3.37	3.70	3.081	3.09	2.82	2.96	1.55
Very wet	1.50–1.99	3.46	3.52	3.26	3.46	3.27	23.14	5.55
Moderately wet	1.00–1.49	6.28	7.31	9.33	8.00	9.91	49.23	8.55
Near normal	– 0.99–0.99	72.22	71.39	74.30	69.27	74.00	24.67	68.36
Moderately drought	– 1.49–1.00	8.93	8.89	8.10	9.00	8.46	0	9.27
Severe drought	– 1.99 to – 1.5	3.10	2.91	1.14	4.82	1.27	0	4.55
Extreme drought	≤ – 2.00	2.64	2.29	7.92	2.36	0.27	0	2.18

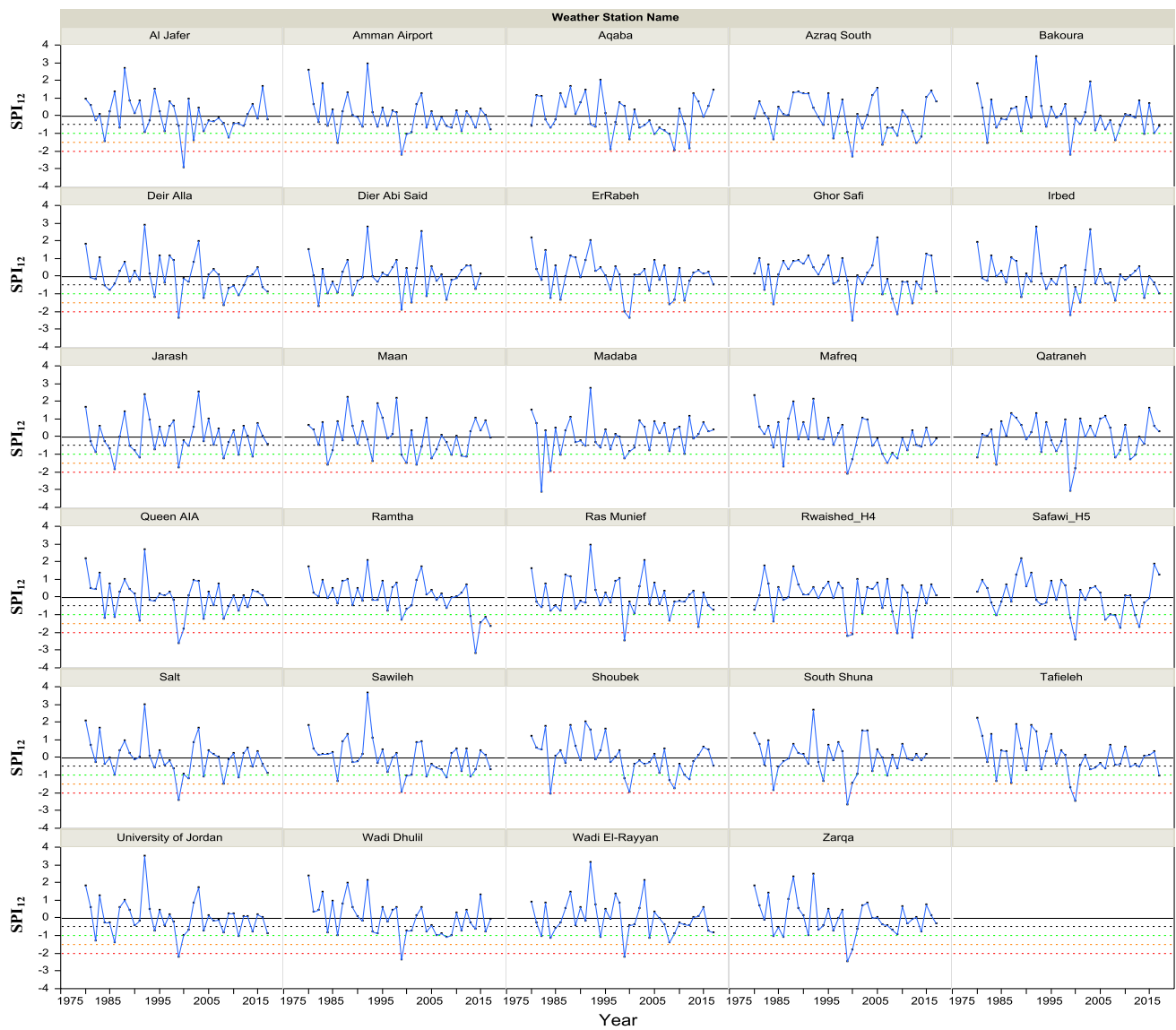


Fig. 4 Annual Standardized Precipitation Index (SPI₁₂) values for each station 1980–2017

by arid to severe-arid type of climate where long-term mean annual rainfall occurs below 200 mm.

Table 4 Linear trend analysis for Standardized Precipitation Index with time

SPI	Linear trend equation	R ²	RMSE	Prob > F
SPI ₁₂	= 40.39 – 0.02*Year	0.0488	0.976	<0.0001*
SPI _{6W}	= 41.06 – 0.02*Year	0.0505	0.975	<0.0001*
SPI _{6D}	= – 3.45 + 0.002*Year	0.0005	0.891	0.4642
SPI _{3AMJ}	= – 1.86 + 0.001*Year	0.0001	0.8774	0.6859
SPI _{3JAS}	= 1.25 + 0.000*Year	0.0001	0.4080	0.9979
SPI _{3JFM}	= 30.69 – 0.015*Year	0.0283	0.9867	<0.0001*
SPI _{3OND}	= 19.12 – 0.010*Year	0.0113	0.9806	<0.0001*

The analysis of annual and monthly time-series rainfall data shows high variation within the same met-station as well as variation among the met-stations (Table 1, Fig. 2). The associated CVs for annual rainfall data ranged from 30.2 up to 83.7% and thus it illustrates the significant variability of rainfall at each met-station. Meanwhile, the positive skewed values and high kurtosis values associated with met-station indicate the presence of high extreme rainfall (wet years than normal) but as a whole the major part of the country receives very less amount of rainfall and thus experiencing hyper-arid conditions (Table 1, Fig. 2).

According to Mann–Kendall test for temporal annual rainfall data of 29 meteorological stations, both the correlation coefficient (*r*) and Kendall τ values are entirely negative which indicates the decreasing trend (except for Madaba

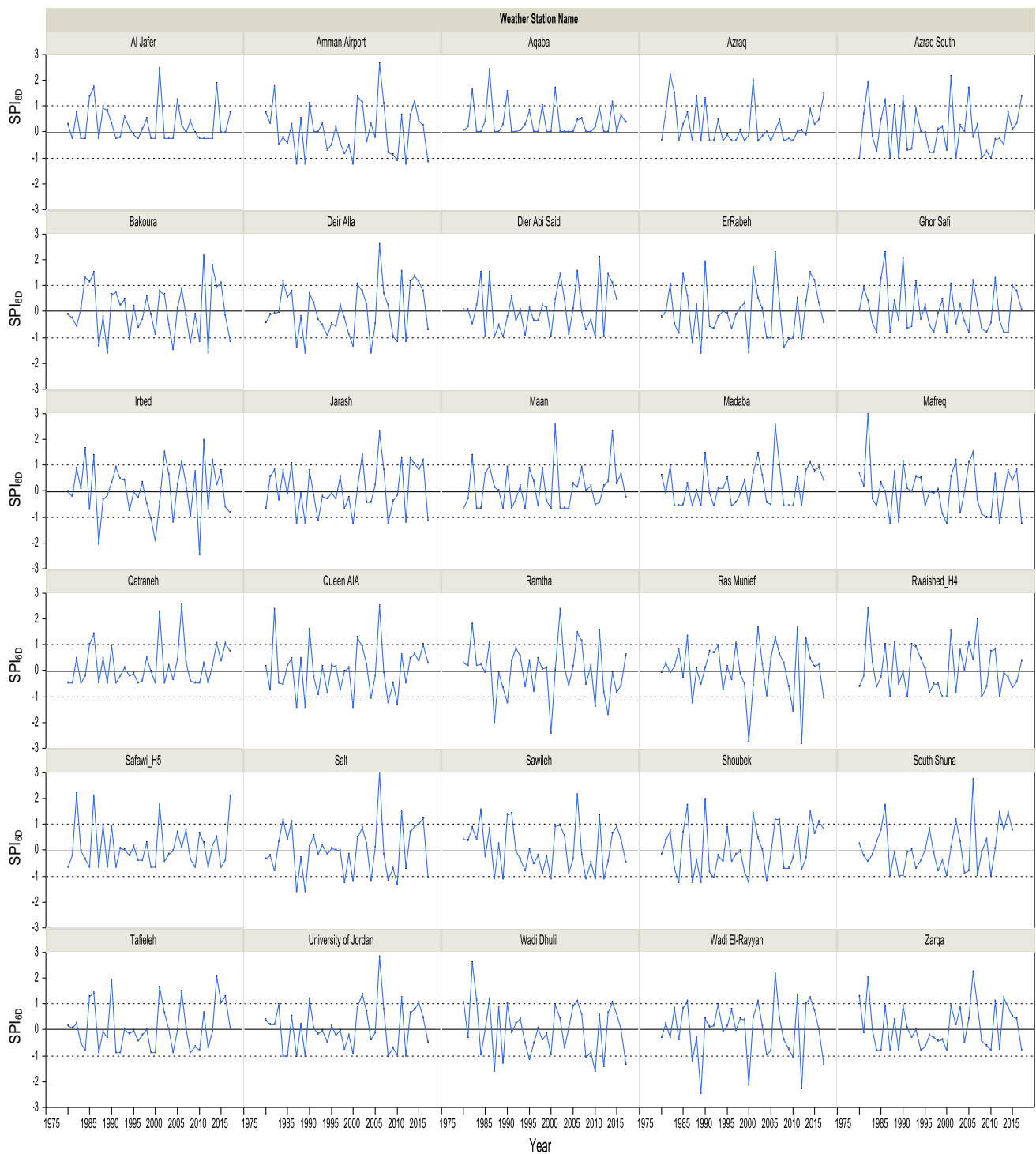


Fig. 5 Dry season Standardized Precipitation Index (SPI_{6D}) values for each station from 1980 to 2017

station) in the amount of rainfall in the country. The most significant trend was found at Mafreq, Queen AIA, Ramtha, Shoubek, and Sweileh weather stations. Similarly, all weather station regression trend shows decreasing trend and the results coincide with Mann–Kendall test results. The

linear trend indicates the average decrease of about 1.8 mm/year for the whole country. On the other hand, Madaba weather station shows non-significant increasing trend in rainfall with time having a mean rate of increase of 0.73 mm/year in the amount of rainfall (see Table 2) (see Fig. 3).

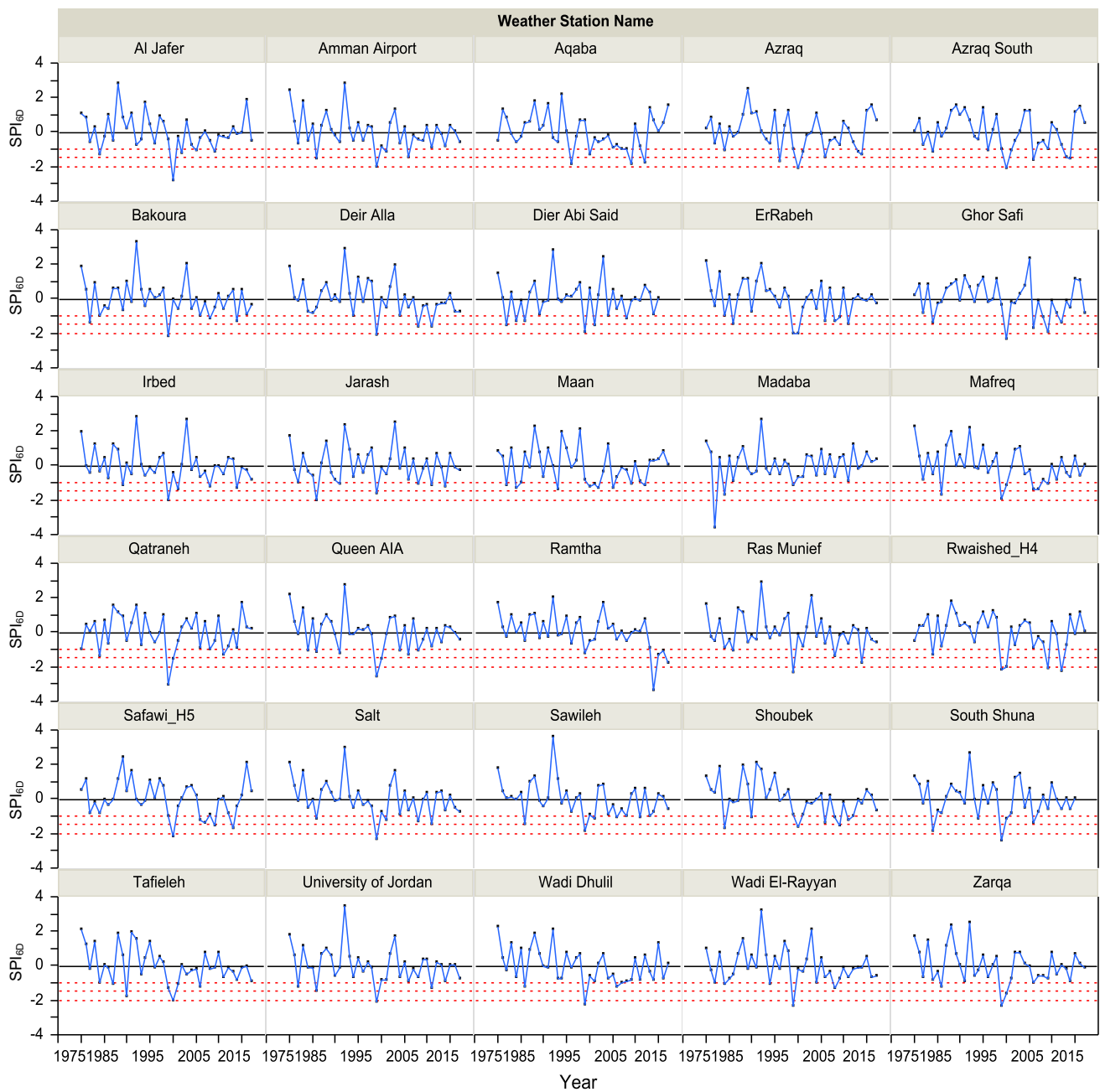


Fig. 6 Dry season Standardized Precipitation Index (SPI_{6D}) values for each station 1980–2017

Table 5 Summary of SPI3 magnitudes for the historical rainfall records from 1980 to 2017

Parameters	SPI _{3AMJ}	SPI _{3JAS}	SPI _{3JFM}	SPI _{3OND}
Maximum	3.064	2.684	2.922	2.632
Minimum	-2.767	0.633	-3.030	-2.787
Mean	0.098	1.253	0.000	0.011
Standard Deviation	0.877	0.408	1.000	0.986

4.2 SPI-12 Variability Assessment

The SPI-12 results indicate that during 1980–2017, 15% of the period has experienced drought conditions having SPI value less than - 1. The drought situation in this period ranges from moderate to extreme drought. Similarly, the wet conditions in the same period were 13% having SPI greater than + 1 varying from moderate to extreme wet conditions. Taking into account, the SPI data show that 50% of the SPI

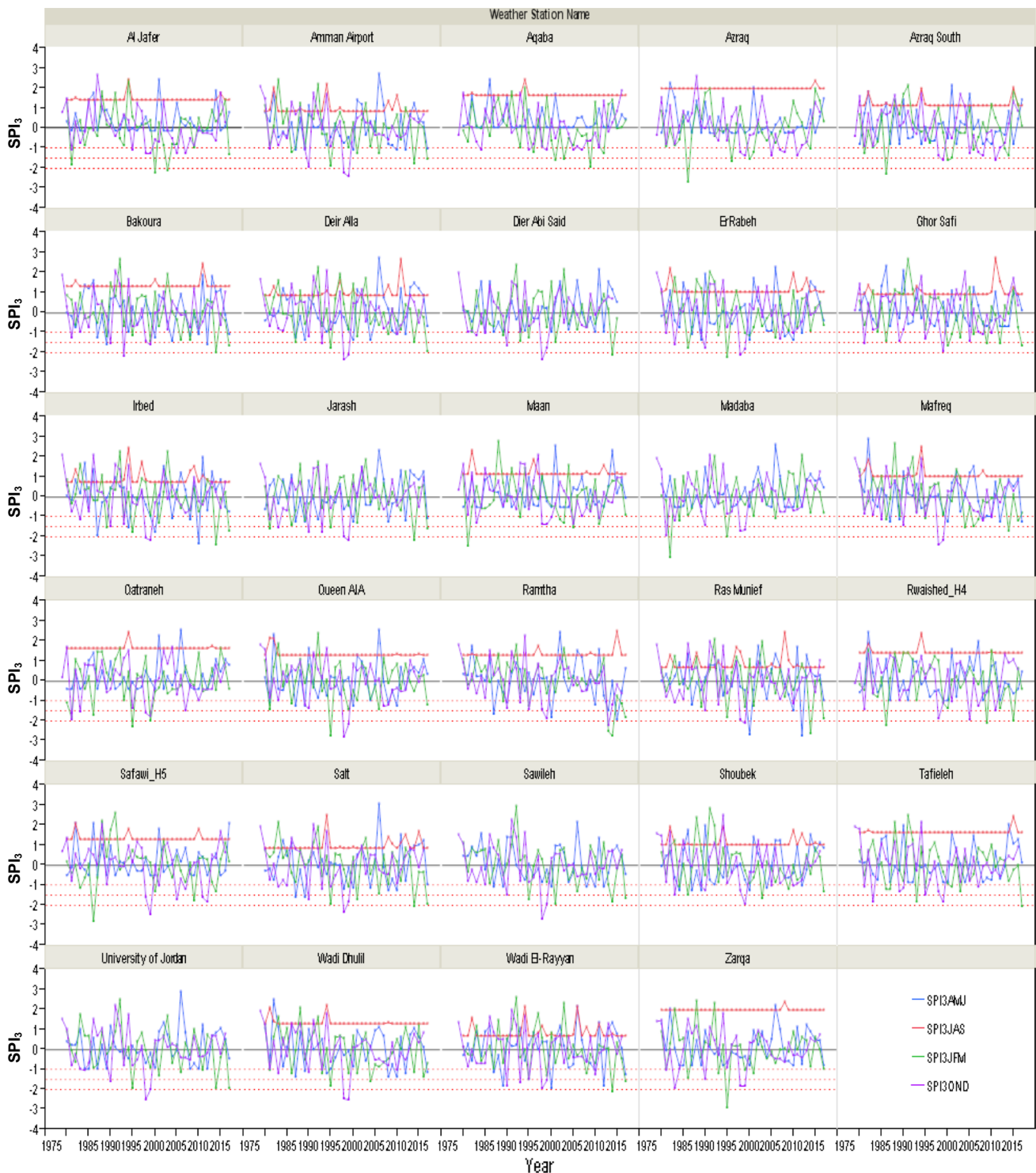


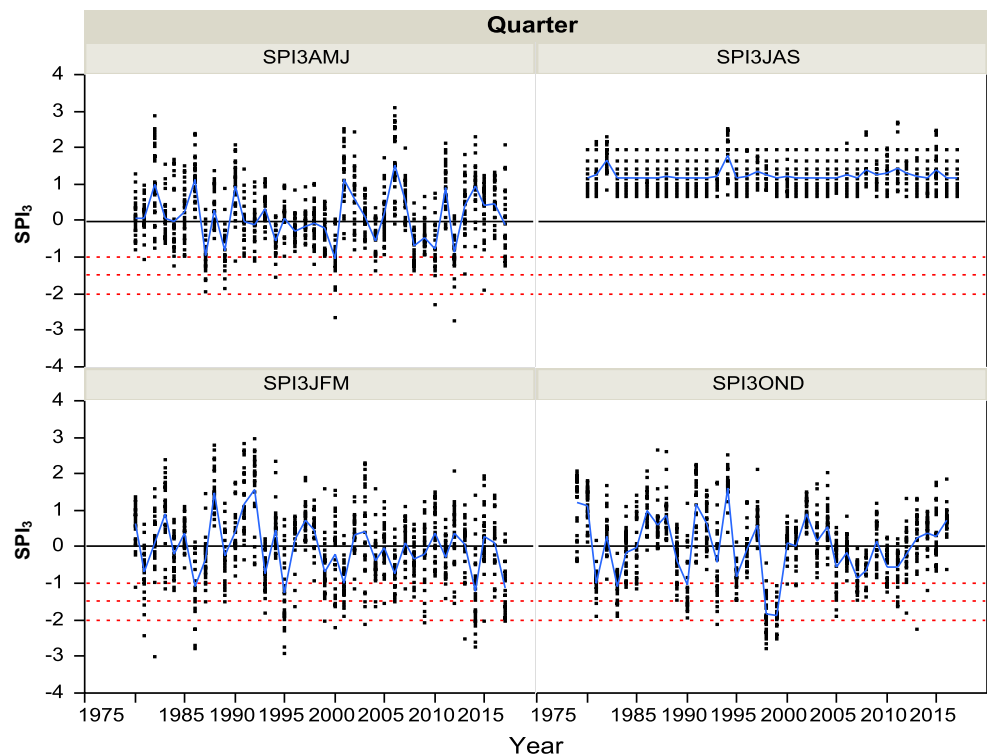
Fig. 7 Standardized Precipitation Index of quarter periods (SPI3) values 1980–2017

values of time-series data are below zero which is also an indication of the prevailing dry conditions in the country (Table 3).

Extreme drought events were observed in the years 1998–1999 all over the country and similarly, extreme

drought was also observed in some stations at the years 1980/1981, 2007/2008, 2010/2011, and 2012/2013. On the other hand, moderate–severe drought events were observed over the years 1980/1981, 1982/1983, 1984/1985, 1988, 1993, 2003–2008, and 2010–2014 (Fig. 4). In terms of

Fig. 8 Overall trend of the Standardized Precipitation Index of quarter periods (SPI₃) values from 1980 to 2017



duration and magnitude, majority of drought events occurs once in every 2 or 3 years. The extreme drought event with highest SPI magnitude of -3.2 was recorded during 2013/2014 at Ramtha weather station.

The linear regression of SPI_{12} indicates the existence of a significant trend of increase in drought magnitude with time in a rate of -0.02 per years ($P < 0.0001$). This indicate the drought events are becoming more frequent and with higher severity (Table 4). As the country is already water scarce having 90% of the area under arid type of climate, this increasing drought condition will further increase the vulnerability to drought.

4.3 Seasonal SPI-6 Variability Assessment

The seasonal SPI-6 was divided into two main seasons, one is dry and other is wet. The dry season SPI-6 shows little variation in time-series data in all the met-stations (Fig. 5). This is because dry season represents the rainfall variability during summer season, where rainfall rarely occurs at the months of April and May. The probability of drought at dry season is 17.2% in the total time-series record from 1980 to 2017 (Table 3). On other hand, based on linear trend the extreme drought events represent 46.2% of total drought events which is the indication of the extreme reduction in the amount of rainfall during this period (Table 4).

Although the lowest annual rainfall occurred during the year 1998/1999, however, the SPI_{6D} results indicates the extreme drought in the year 2012 with a value of -2.8

at Ras Munief met-station followed by the year 2000 with a value of -2.7 for the same station. The drought event at Ramtha station is still considered among the extreme drought of SPI_{6D} at the years 1987 and 2000; in addition to this, Irbid met-station in the years 1987 and 2010, and Wadi El-Rayan met-station in the years 1987 and 2010 have experienced extreme drought conditions.

Investigating the Ras Munief weather station records that is located at the highest altitude in Jordan (1150 a.s.l), it was clear that the rainfall always occurs in April and till beginning of May with an average of about 20 mm in April and 7 mm in May. However, in the years 2000 and 2012 there was no rainfall recorded at the Ras Munief weather station.

The wet season standardized indices (SPI_{6W}) mimic the variability of annual SPI overtime (Fig. 6). This is true as SPI_{6W} represents the variability within about 95% of the rainfall records that falls within wet months (October to March). In similar pattern as annual, the drought has a significant linear trend of increase of about -0.02 per year ($P < 0.0001$).

4.4 Three-month Standardized Precipitation Index (SPI₃) Variability

Table 5 represents the 3-month SPI results for different months, i.e. April, May and June (SPI_{3AMJ}), July, August and September (SPI_{3JAS}), October, November and December (SPI_{3OND}), January, February and March (SPI_{3JFM}). The

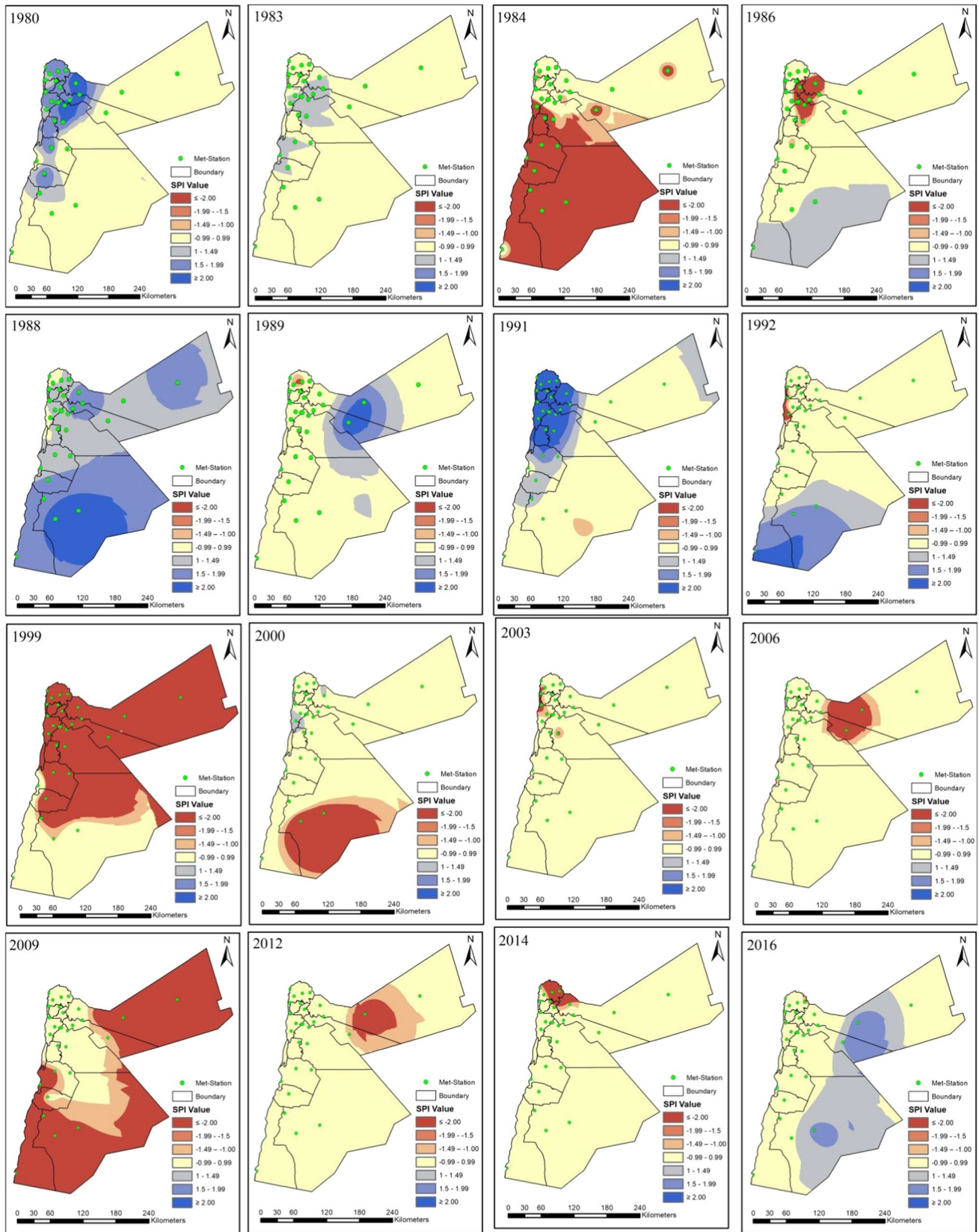


Fig. 9 Spatial SPI Kriging maps generated for the period from 1980 to 2017

Table 6 Multi-linear regression analysis for SPI12 regarding spatial and temporal scales

Weather Station	Estimate	Standard error	<i>t</i> ratio	Prob > <i>t</i>
Time	− 0.020028	0.002686	− 7.46	$P < 0.001^*$
Baqura	− 0.000485	0.157846	0.0	0.9975
DeirAlla	0.0003229	0.157846	0.00	0.9984
Ghor Safi	0.003824	0.157846	0.02	0.9807
Irbid	− 9.885e-5	0.157846	− 0.00	0.9995
ErRabeh	0.0021258	0.157846	0.01	0.9893
Shoubek	0.0013583	0.157846	0.01	0.9931
Tafieleh	0.0012457	0.157846	0.01	0.9937
Salt	0.0002993	0.157846	0.00	0.9985
Aqaba	− 0.000319	0.157846	− 0.00	0.9984
RasMunief	0.0006314	0.157846	0.00	0.9968
Amman Airport	− 0.000698	0.157846	− 0.00	0.9965
Mafreq	0.0006292	0.157846	0.00	0.9968
Safawi H5	0.0023324	0.157846	0.01	0.9882
Queen AIA	0.0013181	0.157846	0.01	0.9933
Maan	− 0.001784	0.157846	− 0.01	0.9910
Al-Jafer	0.0032788	0.157846	0.02	0.9834
Zarka	0.0015815	0.157846	0.01	0.9920
WadiDhuleil	0.0001879	0.157846	0.00	0.9991
Qatraneh	0.0043724	0.157846	0.03	0.9779
Azraq South	0.0030334	0.157846	0.02	0.9847
Reweished H4	0.0076678	0.157846	0.05	0.9613
WadiErRayyan	− 0.000371	0.157846	− 0.00	0.9981
Sweileh	− 0.001671	0.157846	− 0.01	0.9916
Maddaba	0.0037757	0.157846	0.02	0.9809
Ramtha	0.0055731	0.157846	0.04	0.9718
Dier Abi Said	− 0.019975	0.162043	− 0.12	0.9019
South Shuna	− 0.018202	0.162043	− 0.11	0.9106
Jerash	0.0001972	0.157846	0.00	0.9990
University of Jordan	− 0.000684	0.157846	− 0.00	0.9965

*Significant at 95% confidence level (probability < 0.05)

highest variability exists at SPI_{3JFM} followed by SPI_{3OND} , while SPI_{3JAS} has the lowest SPI variability. There is no rainfall recorded in July and the average rainfall in the month of August is only 0.01 mm; thus, the SPI_{3JAS} data show variability only in the month of September. SPI trend analyses (Table 4) indicate that there are significant increasing trends in drought with a rate of $-0.015/\text{year}$ in SPI_{3JFM} and $-0.01/\text{year}$ in SPI_{3ON} . However, SPI_{3AMJ} and SPI_{3JAS} have no trends.

Similarly, the SPI_{3AMJ} represents the variability in spring season that extends from April to June. In Jordan, the rainfall occurs in April and extends to half of the month of May. Therefore, the SPI_{3AMJ} shows variation in these 2 months which range from -2.77 to 3.06 . In terms of drought existence, magnitude, and interval per weather station, the overall

SPI_3 data indicate that the drought in Jordan is mostly visible in the months of October–December and January–March. These periods indicate that the existing drought is not only effective in duration (as expressed by variability between SPI quarters), but rather more effective in severity (magnitude) according to McKee et al. (1993) classification (see Figs. 7, 8).

4.5 Spatial Extent of Drought

The spatial SPI Kriging maps was prepared using Geo-statistical tool within ArcGIS package for the spatial and temporal extent of drought in Jordan during the period of 1980–2017 (Fig. 9). The generated maps showed the presence of two types of drought, i.e. local and national, looking at the extent of the drought event. Local drought is that which exists in a specific area having same climate in a particular season and thus there was no actual observed trend or pattern of occurrence. Local droughts have 1-year extent that may be repeated once in every 4–5 years. On the other hand, national droughts seldom occurred but have full dry extent at all meteorological stations. The existed national drought events had higher overall magnitude than local, and its impact duration may extend to two consecutive years but with very long lag interval. On the other hand, extreme local droughts had higher intensity than national droughts at specific weather stations, and thus imposing severe impacts on local scale geographical locations.

The Kriging semi-variogram analysis indicates that local droughts are anisotropy in its behavior with different angles of impact varying from year to another. In most cases, the drought spatial variation is best fitted exponentially with very negligible nuggets and long major ranges. On the other hand, national droughts had circular distribution fit in an isotropical behavior indicating that national drought is impacting the whole spatial extent of the country with no specific trends in orientation. The location of local drought is reflected by the severity of impact. Local drought in desert areas (western parts of the country) seems more frequent but with low impacts since they are associated with low mean annual rainfall that is less than 50 mm, while local droughts on highlands are more critical as the mean average is more than 400 mm.

4.6 Cluster Analysis

Using multi-linear regression analysis, the ANOVA tables indicated that the effect of the time (year) is more effective than the spatial location as indicated by very significant probability test of $P < 0.001$ for time and non-significant $P = 0.99$ for location (Table 6). Regardless of the location of the drought, the average SPI magnitude increases by time with an average rate of -0.02 per year (R^2 of

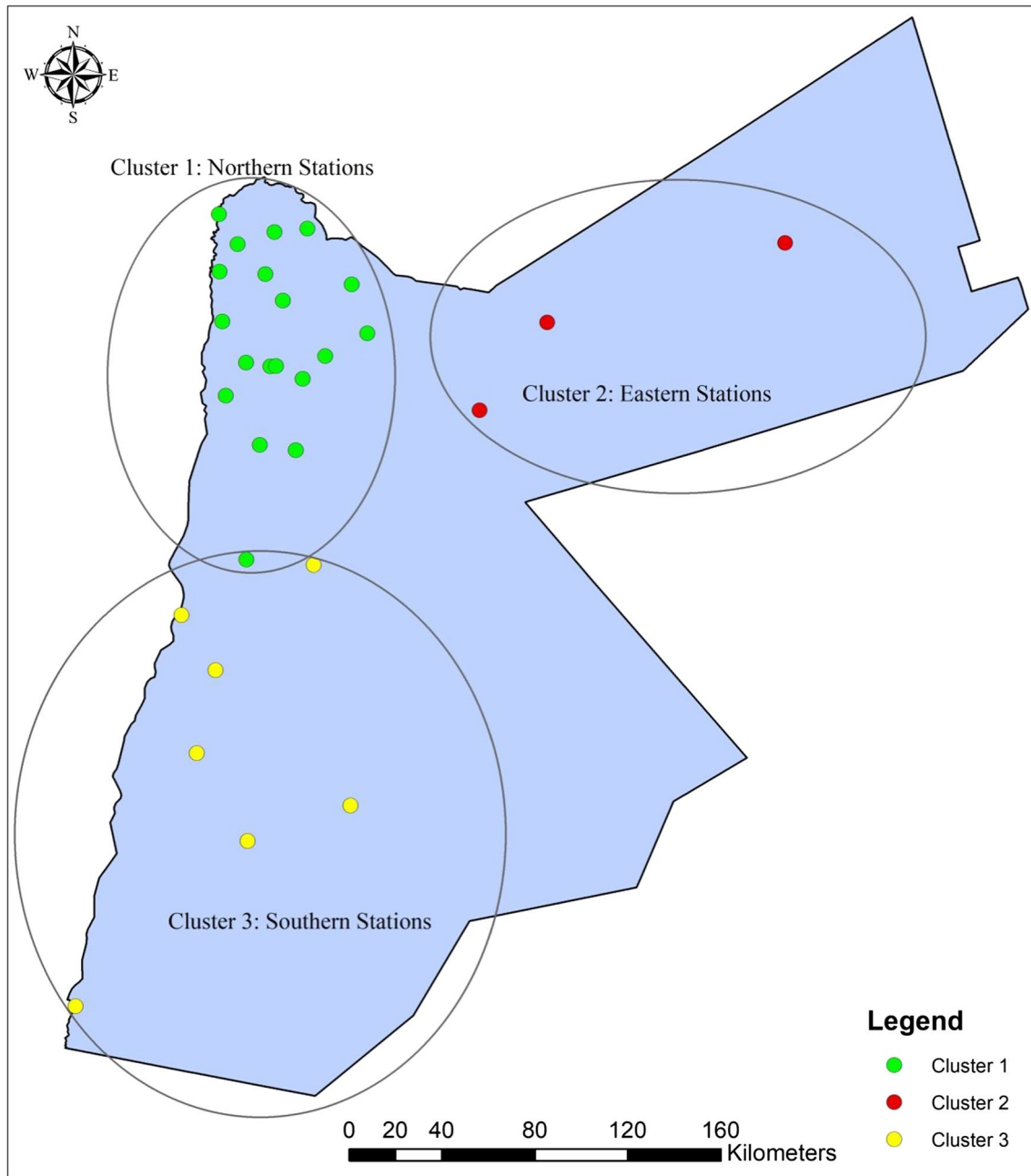


Fig. 10 Drought grouping using Ward's minimum variance method within hierarchical cluster analysis for SPI_{12}

4.79 and RMSE of 0.9896). On the other hand, the spatial effect of drought is clearer in 1 year more than the other, and in some cases there is no significant differences found between weather stations if the country facing a national extreme event (either wet or dry). Using Ward's minimum variance method within Hierarchical Cluster analysis for SPI_{12} , three significant clusters were identified based regardless on the effective year. The dendrogram results illustrated show the grouping pattern achieved

from clustering (Fig. 10). The results indicate that spatial locations of each group (cluster) have similar magnitudes and changes overtime that significantly varies from other clusters.

The generated grouping actually identifies three main regions in the kingdom; the northern, eastern, and southern. Each region has similar micro-climatological conditions. The northern region (green color) is characterized by wet

patterns with rainfall above 250 mm, while the eastern part of the kingdom (red color) represents low rainfall regions with average annual rainfall less than 100 mm, and finally the southern region that is characterized by average annual rainfall less than 250 mm.

5 Conclusions

The results of this study show that Jordan is facing an increasing trend of drought events. Various time scale SPI (12, 6 and 3 months) were used for better understanding of drought occurrence, magnitudes, and severity in the country. The analysis reveals that the amount and duration of rainfall are decreasing. This decreasing trend of rainfall is further exacerbating the issue of water scarcity as well as creating the issue of drought. It is forecasted in the study that the duration of drought events is increasing and the severity will be rather higher in future. The SPI results and spatial maps for whole study period indicate the presence of both local- and national-level droughts. The probabilities of occurrence of local droughts are once every 2–3 years. The intensity of local droughts is more severe than national droughts as indicated at Ras Munief, Ramtha, Irbid, and Wadi El-Rayan met-stations results. On the other hand, extreme national droughts occur once in every 15–20 years and extend for two or more consecutive years. The linear trends of drought magnitude indicated significant increase by time with the rate of 0.02 ($P < 0.0001$). The location of severe to extreme local drought is imposing the need to have a monitoring program to investigate the direct and indirect impacts on all sectors and to develop a proactive risk management approach and preparedness plans for various physiographic regions of the country.

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