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Analysis of Historical Precipitation in Semi-Arid Areas – Case Study of the Amman Zarqa Basin

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ABSTRACT

Climate change is determined as a severe threat to water resource availability in Semi-Arid Areas. Therefore, it is crucial to examine the drought trends to develop and sustain water resources. This study evaluates the effects of climate change in Jordan by investigating the long-term precipitation trends in the Amman Zarqa Basin over the water from 1971 to 2016. Daily precipitation data were gathered to analyze different rainfall stations over and around the basin.. The standardized precipitation index (SPI) variations were investigated at monthly intervals. Control charts, hypothesis testing, T-test, differences of variances, and trend analysis were used to determine climatic trends. The analysis results showed that 2003 marks an acceleration point in the precipitation decrease rate; therefore, the SPI showed a decrease and a high DI for the area in the tested year 2005 and 2010 to be a mild drought in the following years. Additionally, a change in the precipitation pattern was observed as seasonal precipitation contribution varied for the pre-2003 period compared to the post-2003 period. The SPI results show that 1995 reflects the higher drought periods, and the following years showed mild drought events; nevertheless, the year 2016 displayed lower drought events, reflecting wet events.

Keywords: precipitation, climate change, standard precipitation index (SPI), semi-arid.

INTRODUCTION

Countries in semi-arid regions, like Jordan, are characterized by severe water scarcity and high vulnerability to climate change. Climate variation will have unexpected consequences concerning the frequency and intensity of precipitation and temperature variability for many regions of the earth (IPCC, 2007; Trenberth, 2008). Precipitation, air temperature, and velocity are the most critical variables in environmental sciences in general, and exclusively climate sciences and hydrology. Precipitation is the most effective component in the water cycle in rainfall-runoff relationships and groundwater recharge; it also influences flood/drought assessment and mitigation measures (Somsubhra and Edwards, 2015). The implications of precipitation and temperature changes make it essential for water resource decision-makers to consider their plans and impacts on hydrologic variables. Most of water resources projects are planned, designed, and operated based on the historical prototype of water availability, quality, and demand, assuming constant climatic behavior. Therefore, it is essential to investigate the present and probable future climate change patterns and their impacts on water resources to implement appropriate adaptation strategies (Abdul Aziz and Burn, 2006).

Extreme climate conditions are expected to significantly affect arid regions (Giorgi and

Lionello, 2008; Lange, 2019). Different scenarios have been projected for the region for the coming few decades, which can be summarized as, but are not limited to, the following: an increase in mean temperature by 4°C to 6°C, increase in seasonal temperature variability, reduction in precipitation of between 4% to 8%, increase in evapotranspiration by 10%, increased rain intensity and shortened rainy season, higher seasonal temperature variability, increased frequency and severity of extreme events and greater spatial and temporal climatic uncertainty. Over the last three decades, Jordan has detected several different climate change phenomena, including a short rainy season, early spring and summer, frequent occurrence of extreme events, and long-term drought.

During the last century, the rate of climate change throughout the eastern Mediterranean region seems to have been faster than any of the changes over the past events (Houghton et al., 1990), which strongly implies an anthropogenic effect. Alpert et al. (2008) analyzed the results of regional climate modeling of the Eastern Mediterranean region. Those analyses concluded that the average temperature across the Mediterranean region has increased by 1.54°C over 100 years.

In analyzing of decadal trends for the rainfall precipitation pattern in the eastern Mediterranean for 1950–2000, Krichak and Alpert (2005) found a dominant-negative precipitation trend in most of the Mediterranean. According to the locality, the results in other parts of the world showed varying outcome, according to the locality. For example, when determining the long-term trends in annual precipitation and mean annual air temperature for the state of Kentucky, Somsubhra and Edwards (2015) found that significant trends in annual precipitation were detected for only two of the 60 precipitation-homogenous weather stations. In their trend analysis of precipitation data over the Kelantan River Basin in Indonesia, Abdulkareem and Sulaiman (2016) found that there was no statistically significant trend in the annual maximum series of 24-hr precipitation in 12 of the 17 selected rainfall station locations and statistically significant trend in 5 locations for the period of 1984–2014. This could be due to watershed characteristics, such as land-use changes, soil, and topography, of the study area. Rustum et al. (2017) investigated the long-term trends in precipitation from 16 stations located in the lower Shire catchment in Malawi over 1953–2010; they found that the annual precipitation has increased, while monthly precipitation reflects an upward trend in wet seasons (November to April) and a downward trend in dry seasons (May to October). The monthly peak trend analysis has shown an upward trend in rainy months at all stations. When studying the trend analysis of precipitation and drought in the Aegean region, Turkey, Bacanli (2017) found that the monthly precipitation trend decreases in December, January, February, and March in all regions, according to the linear regression analysis results. Droughts have many direct and indirect impacts on various sectors; water resources, agricultural, and environmental sectors are directly impacted; from the other hand, droughts indirectly affect the social and economic sectors, which profoundly change the natural system. Therefore, several indices and methods have been involved in modeling drought in various parameters such as rainfall, temperature, soil moisture, and vegetation index (Palmer 1965, 1968; Shafer and Dezman 1982; Kogan, 1990; McKee et al. 1993, Mohammad 2018). In drought analysis by the SPI, drought is more regular but shorter in short periods, and as the time increases, the duration of drought also increases but the frequency decreases. Winter droughts started to occur in the class of ‚severe' in recent years. In Turkey, the trends in precipitation at annual, seasonal, and monthly time scales for the periods of 1931–2006 were analyzed for the Samsun area on the Black Sea. The results showed no negative or positive statistically significant trend in the study area, despite a slight precipitation decrease in winter for 1931–2006. There was a slight, but not significant precipitation increase from 1974 to 2006 (Karabulut et al., 2008).

Few studies were carried out in Jordan on the subject. Abdullah et al. (2009) used 19 different climate scenarios for the Zarqa River Basin in Jordan to examine the effects of precipitation on the country's water resources. They found that a 10% to 20% increase or decrease in precipitation would significantly affect runoff and groundwater recharge. Hence, it seems that the impact of rainfall change far outweighs the effects induced by temperature change alone. For example, their study indicated an increase in temperature by 1°C, with no change in precipitation would reduce runoff by 1.2%. On the other hand, if rainfall decreased by 10%, the runoff would decrease by 12.2% with no change in temperature.

Moreover, with a 10% decrease in rainfall and a 3.5°C increase in temperature, the runoff would decrease by 15.5%. Furthermore, if precipitation fell by 20%, the runoff would be reduced by

20.8% with no change in temperature and 23.6% for a 3.5°C increase in temperature (Abdullah et al., 2009). Hamdi et al. (2009) indicated no statistically significant positive or negative trends in the annual precipitation level or the maximum temperature based on the data from six meteorological stations in Jordan. Similar findings were previously reported by Bani Domi (2005) and Dahamsheh and Aksoy (2007). Al-Houri studied the variability and trends in daily rainfall over AZB; and found that there was an increasing trend in the maximum and average daily rainfall for most of the stations, but the results of the Mann-Kendall test revealed that none of the parameters under study showed statistically significant trends (Al-Houri, 2014). On the other hand, Hamdi et al. (2009) stated that the lack of significant trends could be due to the absence of detailed meteorological data and the reliability of Jordan's existing data. Mohammad et al. (2018) analyzed the meteorological and hydrological drought indices in the Yarmouk River basin in Jordan for 1993–2014 and found that severe and extreme drought events in most years have harmed the groundwater levels in the targeted area.

STUDY AREA

The Amman Zarqa Basin (AZB) was determined as a case study to review the impact of climate change on the pattern and distribution of rainfall in Jordan. The AZB is one of the vital basins in Jordan, where approximately 70% of the industrial activities in Jordan are carried within this area. It has witnessed a sudden expansion in urban development in recent years, including the erection of numerous buildings and the construction of roads, universities, scattered urban centers, and other infrastructure (Mohammad et al., 2016). Furthermore, significant cities, such as Zarqa, Jarash and Amman, are located in the basin (Figure 1a). The AZB is part of the Lower Jordan River Basin and is located in the northwestern part of Jordan. The AZB covers approximately 4,120 km^2, around 90% of which is located in Jordan, and 10% is located in Syria. Due to the prevailing climatic conditions, the AZB is classified as a semi-arid region. It has a mean average rainfall of 219 mm (Shatanawi and Shammout, 2011), varying from less than 100 mm in the eastern part to about 600 mm in the northwestern part of the AZB. The average temperature in the AZB ranges from 11.5°C in winter to 23.5°C in summer.

The AZB faces many environmental problems, such as land degradation, desertification, deforestation, and groundwater over-pumping and salinization. The base flow has also decreased due to groundwater over-abstraction and the diversion of spring flow for different purposes. It has also been argued that this reduction in base flow could also be attributed in part to climate change (Shammout et al., 2013).

Due to the significance of the AZB to Jordan, it has been studied by local as well as international organizations and research entities. These studies have concentrated on water conservation and quality management; however, none have evaluated the effect of climate change on rainfall, runoff, and water resources (Shatanawi and Shammout, 2011). Therefore, this work tries to fill the gap by determining whether there has been any shift in precipitation pattern and distribution due to climate change or not.

METHODOLOGY

An essential technique deployed in this research was applying the geographic information system

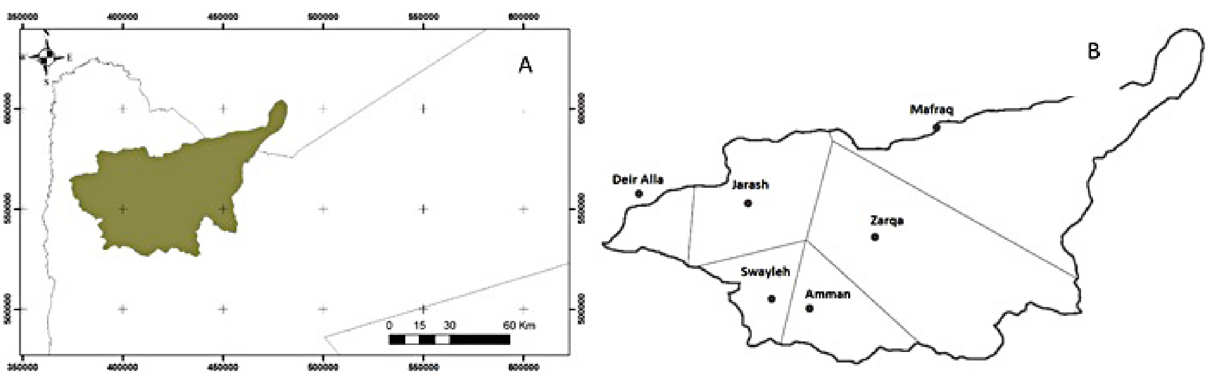

Figure 1. (a) Location of the study area; (b) Catchment areas for the precipitation stations in the AZB according to the Theissen polygon method

(GIS) in hydrological studies, a crucial tool for producing thematic maps. The resulted maps are used to comprehend the spatial distribution of natural phenomena such as water drought (Kam 1995, Mohammad 2018). To start the modeling process, establishing a geodatabase for the weather stations within the targeted area was done; this helps in arranging data for the model; the attributes of this geodatabase were the parameters that the climate stations measured. Thematic maps were generated by interpolating the stations to evaluate the drought index. The software ArcGIS 10.3 has been used for producing the geodatabase, while the spatial analyst extension was used to carry out the interpolation by the kriging method. Kriging is an interpolation method based on regression against observed values of surrounding data points, weighted according to spatial covariance values (Bohling 2005). Annual rainfall records from the rain gauge stations within the targeted area were interpolated using the kriging method in ArcGIS 10.3. The resulted maps were raster maps, and values for each point were counted according to its drought index to create the final maps. The historical data on daily precipitation was obtained for six rainfall stations distributed throughout the AZB from the Jordan Metrological Department and the Ministry of Water and Irrigation of Jordan, covering 1971 to 2016. The rainy season in the AZB generally starts in mid-October and ends in early May of the following year. The years shown in the results indicate the water year (i.e., 1971 covers the period from October 1971 till September 1972). Table 1 shows the names and locations of these stations.

Missing data are frequently encountered in climate variables for many reasons, including failure in the observatory instruments, meteorological extremes, and recording errors. The accurate determination of the climate change effect on climate variables requires the use of full-scale and integrated data recorded by many stations that provide fair coverage of the whole study area.

Table 1. Coordinates and elevations of the six stations used in the analysis of the precipitation changes in the Amman Zarqa Basin

Station	Latitude	Longitude	Elevation (m)
Swayleh	35° 54	32° 00’	1050
Amman	31° 58’	35° 58’	779
Mafraq	32° 21’	36° 15’	683
Deir Alla	35° 37’	32° 13’	-224
Jarash	35° 51’	32° 12’	655
Zarqa	36° 70’	32° 80’	644

Therefore, the normal ratio method was used to estimate the missing historical data for each station. This method is used when the annual precipitation of any surrounding rainfall stations exceeds 10% of the station that is under consideration. To weigh the effect of each adjacent station, the following equation is used (Singh, 1994):

$$P_X = \frac{1}{m}\sum_{i=1}^{m}\left(\frac{N_X}{N_i}\right) \times P_i \tag{1}$$

where: N_i is the annual long-term average of temperature or precipitation for each adjacent station, N_X is the annual long-term average of temperature or precipitation for the missing station, P_X is the missing daily precipitation value, P_i is the estimated precipitation value at a specific day, and m is the number of adjacent stations used for the estimation.

Besides, the areal precipitation over the entire basin was estimated using the Theissen polygon method this tool divides the area covered by the intake point components into Thiessen or proximal zones. These zones symbolize whole areas where any location within the zone is closer to its associated input point than any other input point. Figure 1b shows the locations of six stations relative to their catchment areas based on this method.

Several indicators can be used to analyze the trends iin rainfall's spatial and temporal variation. One of the most popular technical indicators is the moving average method, which predicts trends. Other methods include those related to drought features that occur more frequently in arid and semi-arid areas. In any case, it is necessary to find the best indicators that can describe the rainfall variability and drought severity in a given area. Several drought indices have been developed over the years. Most of them are based only on precipitation, some are based on precipitation and evapotranspiration, while others refer to the runoff and vegetation conditions. These indices are used to evaluate climate variables’ departure in a given time interval (month, season, or year) from the „normal” conditions and are used as monitoring tools and operational indicators for water management. (Mishra and Singh, 2010). One of the most widely used indices in precipitation and drought analysis is the Standard Precipitation Index (SPI) (Karavitis et al., 2012, Zhang et al., 2012). The SPI is based on the probability distribution of precipitation, usually the two-parameter gamma distribution (McKee et al., 1993). It only needs precipitation as input data, can be computed in multiple time scales and is a normalized index, allowing comparability over time and space. The SPI has been applied successfully for drought identification in many parts of the world. For example, Paulo and Pereira (2006) used the SPI for drought identification in Portugal and predicted drought class transitions (Paulo and Pereira, 2008). The SPI is easy to use, because it utilizes precipitation statistics only, where the means and standard deviations of precipitation values are used to calculate standard precipitation series (Zhang et al., 2012). This study uses SPI to quantify the precipitation shortage in the rain periods from 1971to 2016. Monthly rainfall data have been gathered from the Ministry of Water and Irrigation (MWI). Therefore, for SPI computation, the 46 years mean was figured using seasonal rainfall data for the wet season in Jordan, which extends from September to March (of available years). The SPI values of the 6 rain gauge stations in and around AZB area have been interpolated using kriging technique in Arc GIS 10.3 package. The SPI equation is given by:

$$SPI = \frac{(X_i - X_{mean})}{\sigma} \quad (2)$$

where: X_i is the annual precipitation value for a specific time, X_{mean} is the average of the annual precipitation values, and σ is the standard deviation of the annual precipitation values.

Negative values show precipitation deficiencies, while positive values show precipitation excesses above the long-term average. The drought categories given in Table 2 are used for the evaluation and interpretation of the SPI. Generally, the SPI is calculated for precipitation values over 3-, 6-, 12-, 24- and 48-month periods over at least 30 years (McKee et al., 1993).

Table 2. Classification of standard precipitation index (SPI) values (NDMC, http://drought.unl.edu/)

Category	SPI value
Extremely wet	> 2
Severely wet	1.5 to 1.99
Moderately wet	1 to 1.49
Normal or close to normal	-0.99 to 0.99
Moderately dry	-1 to -1.49
Severely dry	-1.5 to -1.99
Extremely dry	< -2

RESULTS AND DISCUSSION

The long-term average of precipitation over AZB is 204.8 mm/yr calculated using the Theissen Polygon method. The average annual long-term precipitation for the rainfall stations representing the entire basin varies between the individual stations due to the vast diversity in the topographic and climatic features of the AZB. The SPI values for the 12 consecutive months for all 46 years of records (1971–2016) are presented in Figure 2. Mapping the SPI showed the different distribution of the index within the targeted

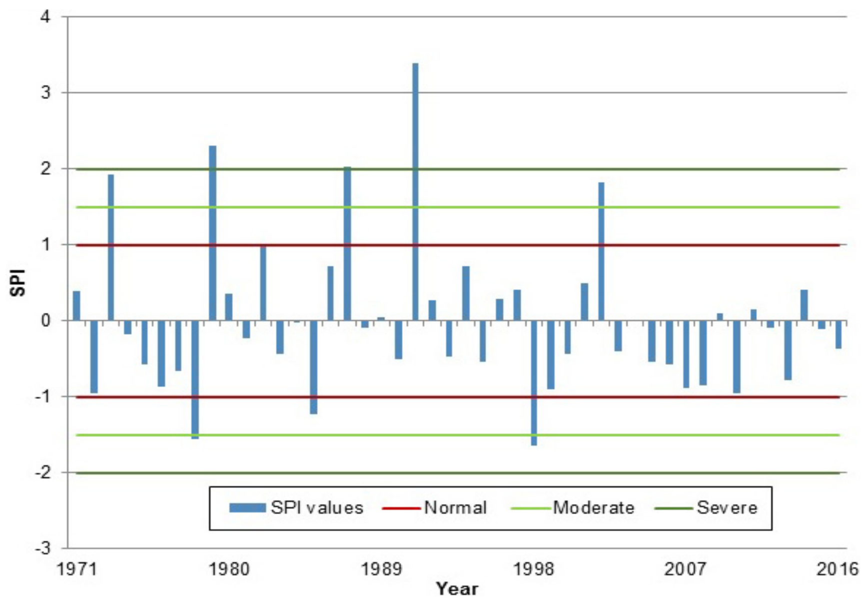

Figure 2. Standard precipitation index classification of mean annual precipitation in the Amman Zarqa Basin, 1971–2016

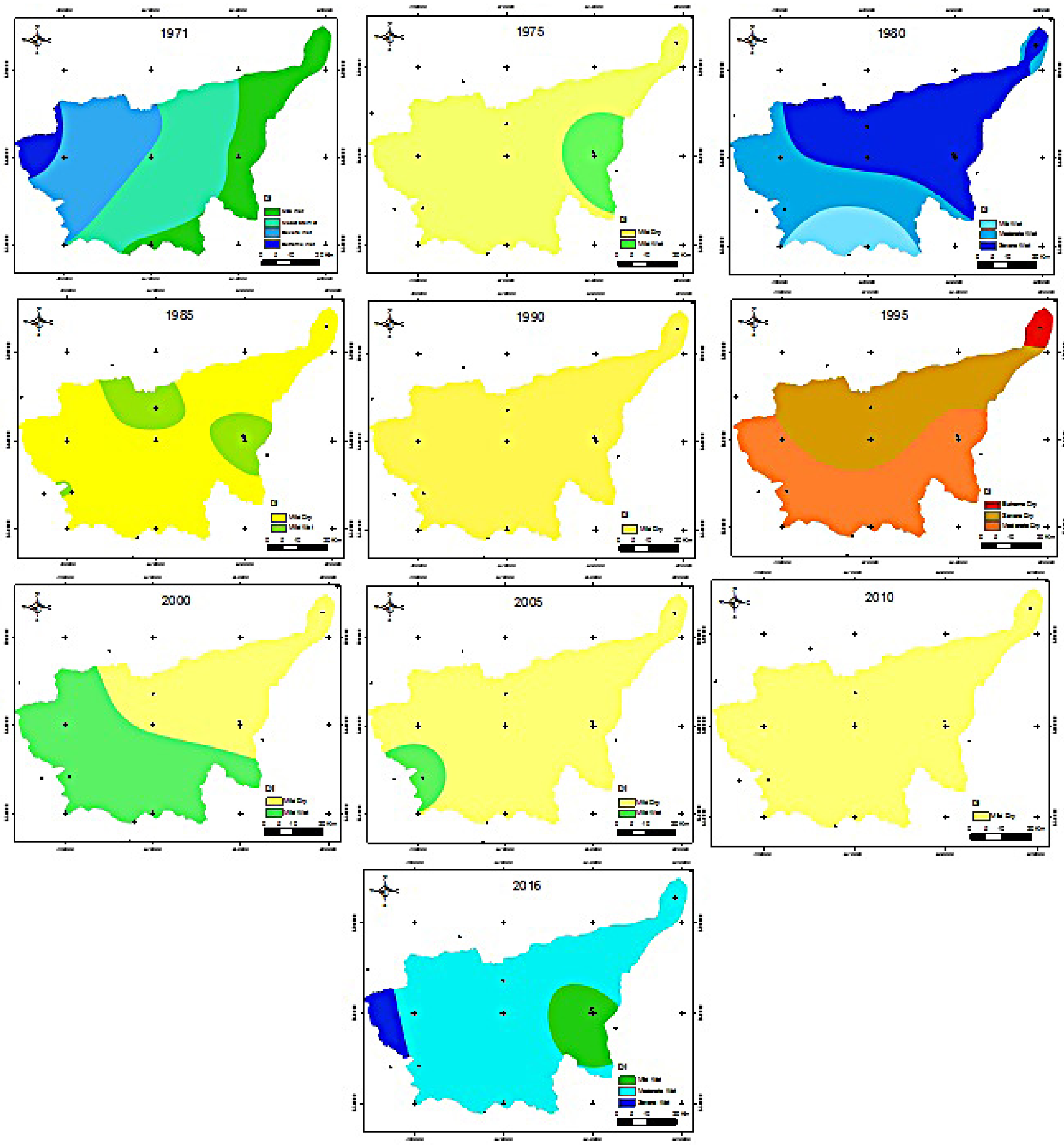

Figure 3. Standard precipitation index mapping in the Amman Zarqa Basin, 1971–2016

area, SPI maps for the basin showed that severe to extreme drought events occurred in 1995; mild dry events were prevalent during the years 1975, 1985, 1990, 2000, 2005, and 2010 as shown in Figure 3, which represents the SPI maps for the targeted area within the selected years. Figure 3 also shows that different years display wet events, starting from 1971, 1980, and 2016. Near normal events in all rainfall stations were recorded in 1985 and 2000, as shown in Figure 3.

The SPI when used at this level of timescale, thus reflects long-term precipitation patterns. As shown in Figure 4a, most of the hydrological years in the AZB are classified as normal or close to normal based on the SPI classification given in Table 2. A slight decrease in the mean average precipitation was observed, as shown in Figure 4b.

Minitab reports several measures of accuracy; MAPE, MAD, and MSD. Mean absolute percentage error (MAPE) is the average absolute percentage change between the predicted value and the true value. Mean absolute deviation (MAD) is the average absolute difference between the predicted and the true values. Mean squared deviation (MSD) is the average squared difference between the predicted and true values (Montgomery

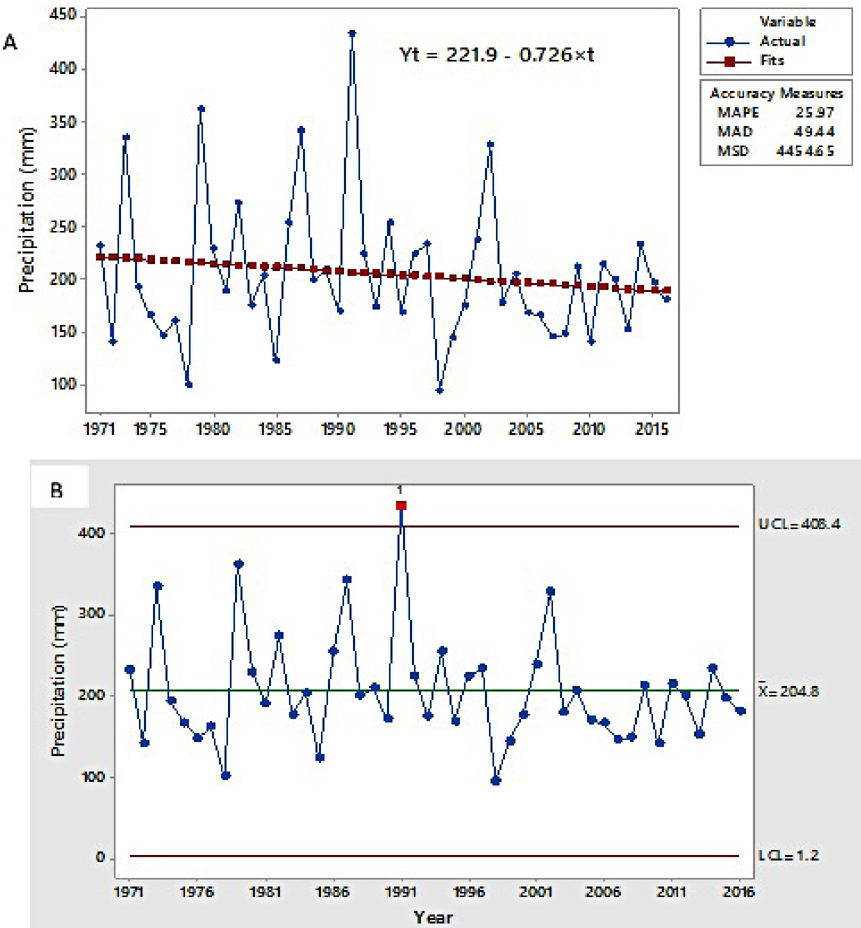

Figure 4. (a) Average of mean annual rainfall distribution in Amman Zarqa Basin, 1971–2016; (b) AZB total annual precipitation for the period 1971–2016

et al., 2015). Plotting the total annual precipitation of AZB on an individual control chart indicates that the year 1991 was an outlier (extreme value). However, further observation suggests that around the year 2003, a change in the data behavior showed a decrease in variability and the mean. It was noted that the year 1991 is no longer considered as an outlier.

The data were visually inspected, and it was observed that the variability of precipitation had reduced in the post-2003 period. To formally affirm this observation, tests for equal variances for the precipitation data captured before and after 2003 were conducted. The statistical test results reported a p-value of 0.000, indicating the variances are statistically different. The data were plotted on the I–chart (Figure 4a, 4b) with dividing the data into two stages; Stage 1: Pre-2003 period and Stage 2: Post-2003 period. Table 3 shows the results of the statistical analysis performed. Local and regional changes in the precipitation characteristics depend on atmospheric circulation patterns of variability, some of which are associated with climate change (Trenberth, 2008). As a

Table 3. Statistical analysis for stage 1 and stage 2 equal variances for the AZB

Stage	N	Standard deviation	Variance	
1	32	77.639	6027.829	
2	14	29.331	860.313	
Null hypothesis			H_0: $\sigma_1 / \sigma_2 = 1$	
Alternative hypothesis			H_1: $\sigma_1 / \sigma_2 > 1$	
Significance level			$\alpha = 0.05$	
Method	Test statistic	DF1	DF2	P-Value
F	7.01	31	13	0.000

result, there is high confidence that many semi-arid areas, including the Mediterranean, will suffer a decrease in water resources due to climate change (IPCC, 2007).

Additionally, hypothesis testing was applied to the annual rainfall data to determine whether there was any statistical evidence which supports the claim that the precipitation data for the period 1971–2002 (Stage 1) differed from the precipitation data for 2003–2016 (Stage 2). The null hypothesis H_0 states that the means of two samples are equal, whereas the alternate hypothesis H_a states that the precipitation mean of Stage 1 is greater than that of Stage 2. A two-sample T-test was used. The result shows a p-value of 0.019, indicating a statistically significant decrease in the mean. Table 4 shows the results of the statistical analysis performed. Similar results were seen when testing each station individually, as shown in Figures (5a and 5b) for Amman Station, representing semi-humid areas.

Figure 6a presents the monthly pattern of accumulated rainfall in the AZB, together with the mean monthly distribution of rainfall. It can be seen that more than a 50% accumulation occurs in January in the middle of the rainy season. The mean monthly rainfall values are symmetric around the mid-season peak and have a clear, simple bell pattern. Further observation of the data revealed that most of the annual rainfall begins in December and ends in February. The amount of rain that falls in this period, based on the long-term average values, accounts for approximately 70% of the total rainfall.

Regarding seasonal distribution, there is a clear change in the rainfall distribution pattern

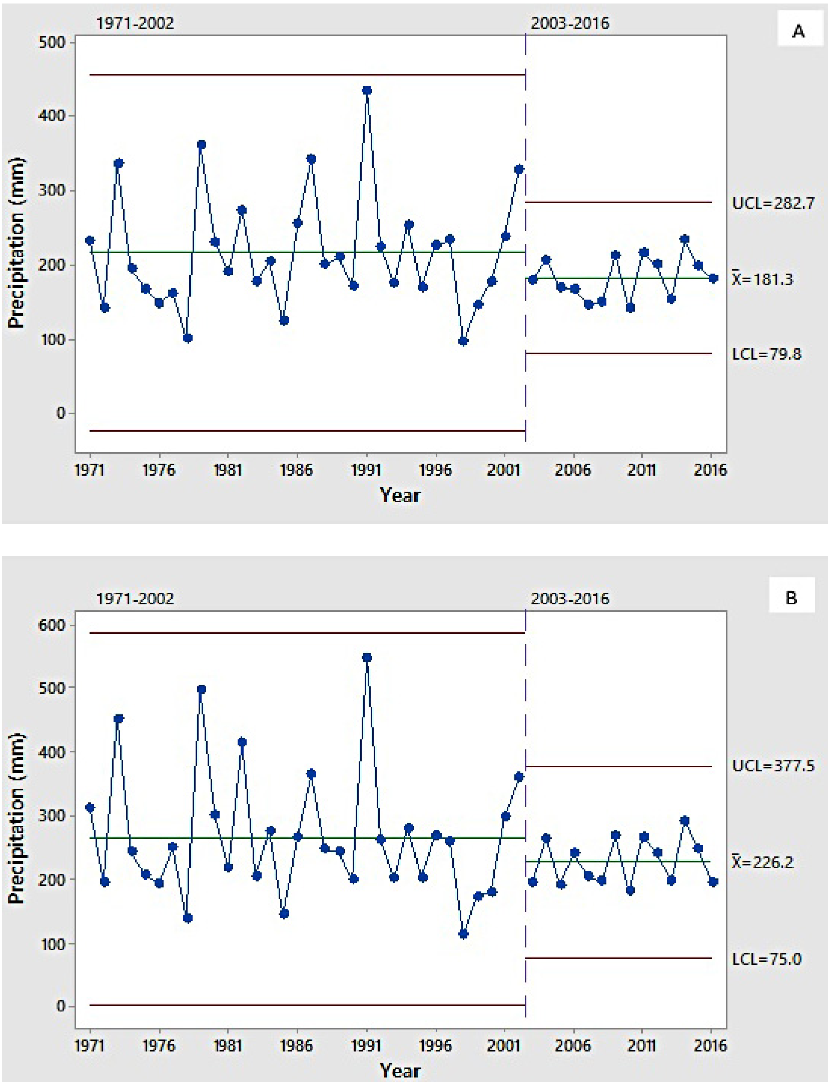

Figure 5. (a) Stage 1 and Stage 2 of the AZB total annual precipitation, 1971–2016; (b) Stage 1 and Stage 2 of Amman total annual precipitation, 1971–2016

Table 4. Statistical analysis for Stage 1 and Stage 2 precipitation mean for the AZB

Stage	Sample Size	Mean	Standard deviation	Square error mean
1	32	215.1	77.6	14
2	14	181.3	29.3	7.8
Null hypothesis		H_0: $\mu_1 - \mu_2 = 0$		
Alternative hypothesis		H_1: $\mu_1 - \mu_2 > 0$		
t-value	Degrees of freedom	p-value		
2.14	43	0.019		

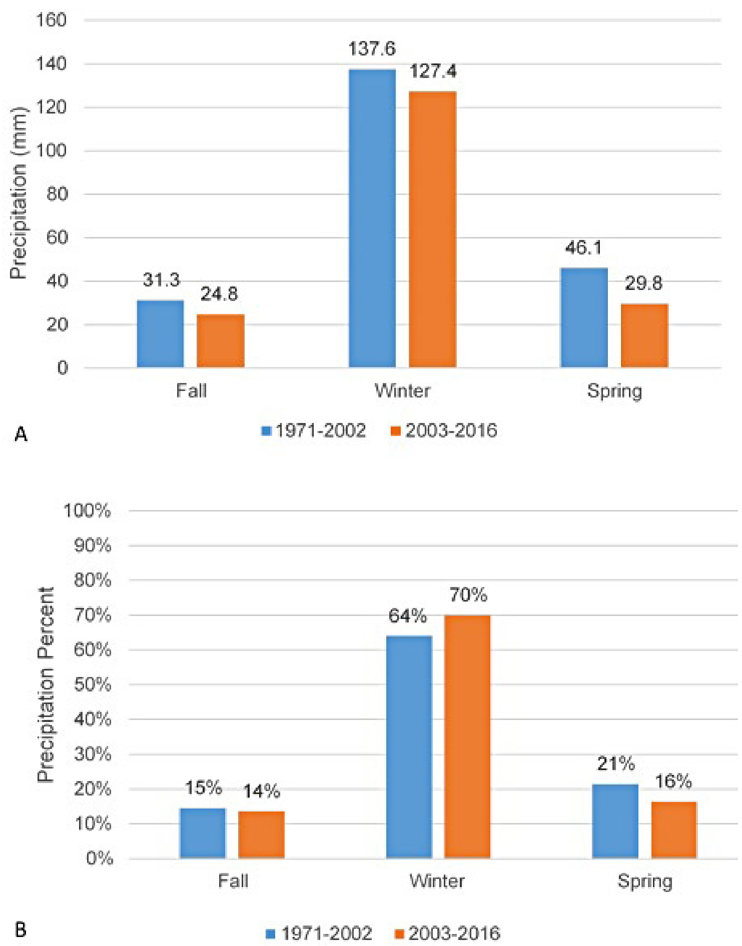

Figure 6. (a) Variation in the seasonal distribution of rainfall distribution in the AZB; (b) Variation in the seasonal total precipitation distribution in the AZB

between 1971 and 2016. This change in rainfall distribution is particularly evident in the last studied years as shown in Figure 6a, where the winter season shows the increased contribution to the annual rainfall average increasing from 64% to 70%, the amount of rainfall in the spring dropped from 21% to 16%. In comparison, the fall season showed a slight drop from 15% to 14% change

Although there is an exact change in the percent of the precipitation that falls during the different seasons, a statistical difference could not be proven when performing the Two-Sample T-test using a level of significance of 5%.

Additionally, the amount of rain that falls during each season was compared, as shown in Figure 6b. The results clearly show a reduction in the total precipitation during all seasons. A hypothesis test was used to determine whether there was any statistical evidence to show that the total precipitation for the period 1971–2002 (Stage 1) differed from the total precipitation for 2003–2016 (Stage 2) for each season. The data were plotted on the I–chart (Figure 7).

The hypothesis testing procedure was applied to the annual rainfall data for the two periods. The null hypothesis H_0 states that the two means of

Table 5. Stage 1 and stage 2 two-sample T-Test and CI statistics for the AZB spring season

Stage	Sample size	Mean	Standard deviation	Square error mean
1	32	46.1	20.5	3.6
2	14	29.8	21.3	5.7
Null hypothesis		$H_0: \mu_1 - \mu_2 = 0$		
Alternative hypothesis		$H_1: \mu_1 - \mu_2 > 0$		
t-value	Degrees of freedom	p-value		
2.46	44	0.009		

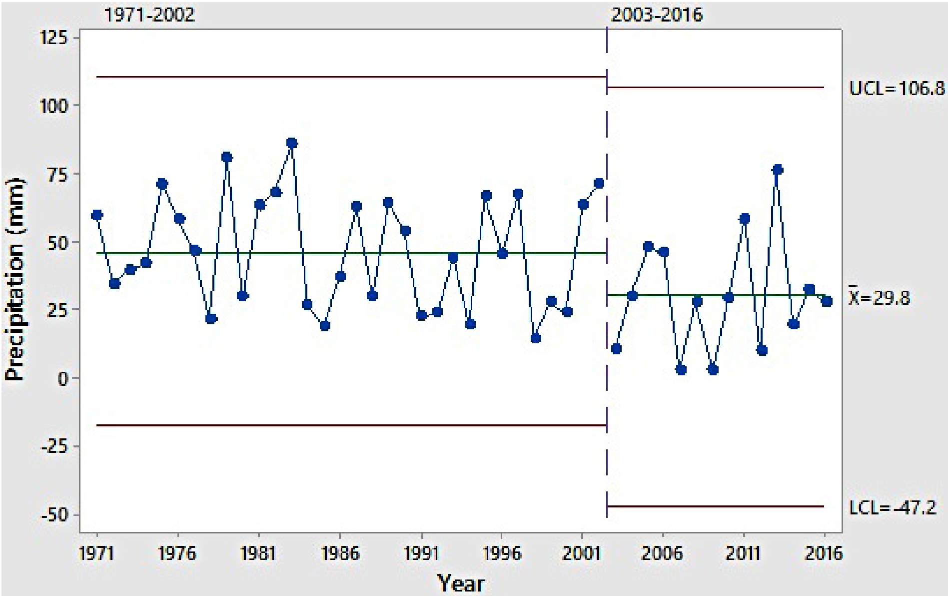

Figure 7. Stage 1 and Stage 2 of AZB total annual precipitation during spring, 1971–2016

the two samples are equal, whereas the alternate hypothesis H_a states that Stage 1 is greater than Stage 2. A two-sample T-test was used, because the sample size was relatively small. A level of significance of 5% was used for both cases; the results show a p-value of 0.009, indicating a significant decrease in the mean. The years 1971–2002 had a mean of 46.1 mm, while the years 2003–2016 had 29.8 mm. Table 5 shows the statistical analysis performed.

CONCLUSIONS

On the basis of the precipitation data analysis for the AZB for the years from 1971 to 2016, most of the years can be classified as normal or close to normal based on the SPI classification. The analysis showed that the year 2003 marks a year for change in data behavior, where data decreased variability. On the basis of the SPI classification, the post-2003 period is classified as normal or close to normal. Additionally, a significant change in precipitation for the period post-2003 (from 1971–2002) compared to the period pre-2003 (2003–2016) was observed. The period from 1971–2002 had mean total precipitation of 215.1 mm, while the period from 2003–2016 had a statistical lower mean total precipitation of 181.3 mm. The total precipitation for the fall, winter, and spring seasons had reduced from 31.8, 137.6, and 46.1 mm to 24.8, 127.4, and 29.8 mm, respectively. The results showed an apparent change in the seasonal precipitation distribution pattern during the years 1971–2016. The winter season for the pre-2003 period compared to the post-2003 period; results showed an increased contribution to the annual precipitation from 64% to 70%, whereas the contribution in spring dropped from 21% to 16% and in fall season from 15% to 14%. This positively indicates the changes in the precipitation pattern between the different seasons during the past 46 years, which means that the short rainy season had become more pronounced in the winter. This trend has been noted over the post-2003 period, where the annual rainfall is classified as falling within the normal category.

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