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Potential Impacts of Climate Change on the Drought Conditions in Jordan

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ABSTRACT

The objective of this study is to assess the potential impacts of climate change on drought severity in the three climatic regions of Jordan (Jordan Valley, Highlands and Badia regions). Monthly precipitation time series (1970-2005) for Irbid, Baqura and Amman stations were used for the estimation of Standardized Precipitation Index (SPI) (drought index). The 5th generation of the ECHAM general circulation model (ECHAM5OM) has been used to estimate the precipitation changes for the period (2020-2055) for the climate change scenario SRES A2. The SPI computed at various time scales (1 month, 3 months, 6 months and 12 months) was used as an indicator of meteorological drought for the present-time and future climate conditions. The study revealed that the three regions behave differently with regard to drought characteristics due to precipitation change under climate change. The results indicated that the moderate/extreme drought months will be slightly decreased in Irbid region in the future under climate conditions. However, Amman and Baqura moderate/extreme drought conditions are expected to be increased under climate change. Also, the results revealed that these regions will suffer from longer-duration drought in the future under climate change scenario compared to that of historical droughts. It is expected that the frequency of drought duration of more than 6 months will be increased in all investigated regions.

KEYWORDS: Climate change, Drought pojection, Drought index, SPI, Trend analysis, Jordan.

INTRODUCTION

Drought is mainly caused by low rainfall and high evaporation rates. It can be characterized as a deviation from average conditions in the ecosystem, which is reflected in some hydrological compnents, such as rainfall, surface runoff and soil moisture. Drought is a natural phenomenon that can vary spatially and temporally from one climatic region to another (Tallaksen and van Lanen, 2004; Wilhte, 2000). Droughts are classified to be amongst the climate hazards that affect almost every country (Oliver, 2005; Svoboda et al., 2002). It is well known that the most severe consequences of drought are usually found in arid or semi-arid regions, where water availability is below average conditions. Countries located in these regions are very vulnerable and have low adaptive capacity to mitigate drought conditions.

Climate change (CC) is expected mainly to affect climatic variables, such as precipitation and temperature. Accordingly, drought frequency, duration and severity will be impacted by CC. So, it is important to understand how thsese changes in drought characterstics will affect the water cycle components; i.e., soil moisture, groundwater recharge and surfcae runoff. The International Panel of Climate Change

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(IPCC) in its 4th assessment report (IPCC, 2007) provided a summary of current changes in hydro-climatological parameters. Observed data of global surface temperature indicated that the period (1995-2006) ranks among the warmest years in the records of the last 170 years.

In the last 50 years, changes in extreme temperatures have been observed worldwide. Most global climate models predict a clear change in precipitation, supported by decreasing trends in rainfall (Freiwan and Kadioglu, 2008). These changes resulted in high frequency of low flows and hydrologic droughts (Hisdal et al., 2001; Smakhtin, 2001). Although several drought studies were carried out using hdrological indices, only few of them were based on meteorological drought indices (i.e., Kothavala, 1999; Blenkinsop and Fowler, 2007; Mavromatis, 2007).

Global hydrological cycle will be seriously affected by CC and more extreme events, either floods or droughts, become more frequent (Hisdal et al., 2001). The recent projections of future climate change scenarios based on various general circulation models (GCMs) indicate significant changes in temperature and precipitation patterns (Houghton et al., 2001). For many regions of the world, the models predict an increase in temperature and a decrease in precipitation, which will lead to further increases in drought magnitude and frequency in those regions.

None of the climate change studies conducted in Jordan addressed climate change impacts on drought conditions in Jordan (Abdulla and Al-Omari, 2008; Freiwan and Kadioglu, 2008). Most studies focused on analyzing and modeling precipitation and using precipitation in rainfall-runoff modeling (Al-Qadami and Abdulla, 2019; Abdulla and Al-Qadami, 2019; Hadadin, 2016; Arabeyyat et al., 2018; Al-Amoush et al., 2018). This study aims at assessing the impact of climate change on drought conditions in Jordan climatic regions.

Several drought indices have been used to study drought (Keyantash and Dracup, 2002; Heim, 2002). Of these, the most common indices used worldwide are the SPI index (McKee et al., 1993) and the Palmer Drought Severity Index (PDSI) (Palmer, 1965). Descriptions of these indicies can also be found in Alley (1984). The SPI index is the transformation of the precipitation value aggregated over a selected period (usually from 1 to 24 months) into a standardized normal distribution (e.g., Oguntunde et al., 2017; Leng et al., 2015; Lana et al., 2001; Hayes et al., 1999; Seiler et al., 2002) and has become an important indicator in various drought monitoring studies.

STUDY AREA AND DATA

Jordan climate is classified as Mediterranean type; it is described by a hot dry summer and a cool wet winter (Abdulla and Al-Qadami, 2019). The winter season starts by October and ends by May. Jordan is located within 80 km east of the east Mediterranean Sea; it extends between latitudes 29º 10' N and 33º 22' N and between longitudes 34º 59' E and 39º 18' E. The geographical and topographic features of the country contribute to a classification of the following three main bio-climatic regions (Abdulla and Al-Qadami, 2019) (Figure 1):

- The Jordan Valley and southern Ghors: thin lined lowlands with an altitude ranging from 200 to 400 meters below sea level. Often considered the "food basket" of the country, its fertile lands allow for fruit and vegetable production for the local and export market.

- The Highlands: this area is heavily urbanized and receives the highest rainfall. Most of the rain-fed agriculture of the country is based here, producing wheat, barley, pulses and some fruits.

- The Badia and Desert region: it covers approx. 75% of the territory, with mostly livestock-based agriculture and some cultivation in the watershed vicinity or supported by deep bore irrigation.

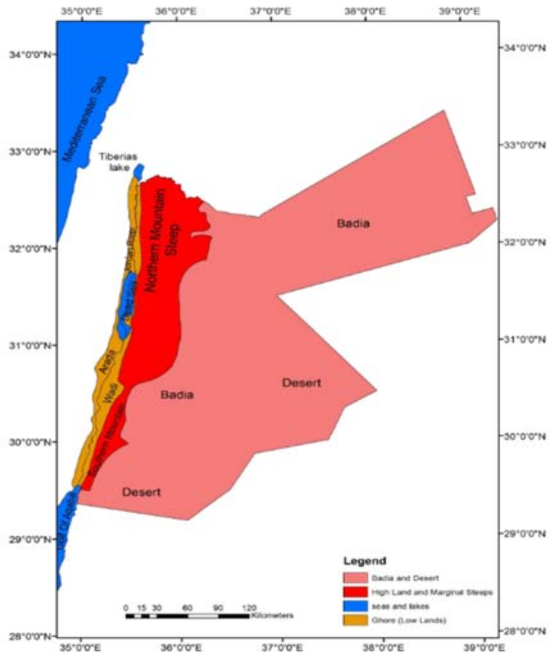

Figure (1): Climatological regions of Jordan (Abdulla and Al-Qadami, 2019)

Three climatic stations (Table 1) were selected in a way to represent the three climatic zones of Jordan. The selection was based on at least 40 years of record. The monthly data of precipitation for these climatic stations was obtained from the Ministry of Water and Irrigation.

METHODS

Data Analysis

Analysis and screening of the climatic data of these stations were performed. Accuracy, completeness and consistency checks of the data were carried out using the well known hydrological procedures, such as double mass curve analysis and the normal ratio method for filling the missing daily rainfall data. Statistical analysis of the data was performed for each station in each climatic zone. In addition, trend identification for monthly rainfall was performed.

Development of Climate Change Scenarios

Outputs from GCM runs were used to evaluate the impact of climate change on drought charctersitics in Jordan. In this study, the 5th generation of the ECHAM5OM and Statistical Downscaling Model (SDSM4.2) (Wilby et al., 2002) are used to create future projection of precipitation scenarios for the three stations for the period (2020-2055). In this research, the SRES A2 family of scenarios was employed to estimate future CC scenarios. The SRES A2 scenario is of a more heterogeneous world (Nakicenovic and Swart, 2000).

The performance of the statistical downscaling model (i.e., SDSM) was assessed for its ability to reproduce the current and future values of precipitation. Observed data of precipitation from the Ministry of Water and Irrigation was used to carry out statistical downscaling for Irbid, Baqura and Amman climatic stations. Two sets of analysis time windows were selected, covering the periods (1970-2005) and (2020-2055) to evaluate the capability of SDSM.

Table 1. List of selected stations

ID	Station Name	PGE	PGN	Altitude (a.m.s.l.)	Record period	Time step
AE0001	Irbid	230	1218.5	585	1970- 2005	Daily &Monthly
AL0019	Amman Airport	243.5	1153.8	790	1970-2005	Daily&Monthly
AD0032	Baqura	224.4	206.3	-205	1970-2005	Daily& Monthly

PGE : Palestine Grid East. PGN: Palestine Grid North.

Drought Analysis Method

In this study, the standardized precipitation index (SPI) developed by Mckee et al. (1993) was used. The SPI is calculated based on the gamma probaility distribution of precipitation for pre-determined monthly time scales. In this study, one-month, three-month, six-month and tweleve-month SPIs were calaculated by fitting a gamma distribution to each monthly time scale separately. The reason behind the adoption of gamma distribution in this study is due to its ability to fit the monthly precipitation (Wilks and Eggleston, 1992). The procedure of calaculating the SPI using the fitted gamma distribution was documented by Loukas and Vasiliades (2004), Mckee et al. (1993) and Mishra and Desai (2005).

RESULTS AND DISCUSSION

Precipitation Analysis

Analysis and screening of the climatic data of these stations were performed. Accuracy, completeness and consistency checks of the data were conducted using the well known hydrological procedures, such as double mass curve analysis and the normal ratio method for filling the missing daily rainfall data. The results indicated that the annual precipitation varies significently among the climatic regions. As expected, the mean annual rainfall in the Jordan valley (Ghore region) is less than that of the Mountainous region. The amount of annual precipitation in the Mountainous region exceeds 550 mm in the north and decreases to about 230 mm in the south. However, in the Steeps region and Badia region, the amount of rainfall is about 100-200 mm and 75-110 mm, respectively. In the Desert region, the annual rainfall is less than 35 mm.

Trend analysis using the linear trend test and the sequential version of the Mann-Kendall rank trend test indicated a decreasing trend in Baqura station during the period (1975–1991), then a slight increasing trend during the following period up to 2005. Also, Irbid station revealed a significantly decreasing precipitation trend at the 99% confidence level. The decrease seems to be about 10% within a clearly distinguished period (1970-1985). In the next period (1985-2006), there are few alternative short periods of both increasing and decreasing trends. Amman station (Figure 2) exhibited a well distinguished period of decreasing precipitation trend of about 8% since 1970 up to the year 2005.

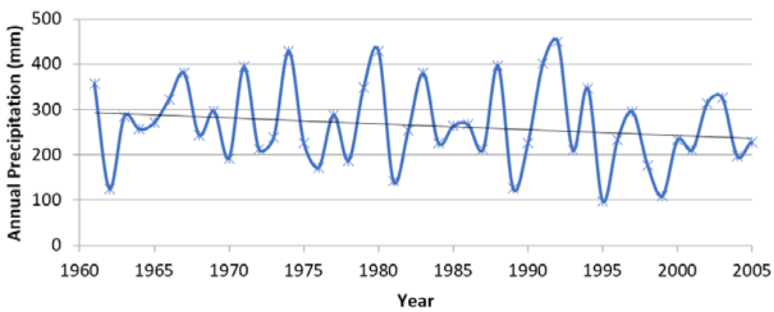

Figure (2): Annual precipitation of Amman station and its linear trend

Climate Change Scenarios

In this study, the A2 family of scenarios was selected to estimate future projections of climate-change scenarios. The climate-change scenarios of precipitation were derived from the outputs of ECHAM5OM GCM-simulated time series for the base line scenario (1970-2005) and GCM projection (2020-2055). In this study, one future period was selected to study the impact of climate change on drought characteristics (2020-2055). The ECHAM5OM predicts a decrease in precipitation in the cold and rainy months for all stations. For example, Figure 3 shows the percent reduction in the projected precipitation under scenario A2 for the future period (2020-2055) as compared to the baseline period (1970-2005). As can be seen, the reduction in the rainy season ranges from 9% in January to about 24% in February.

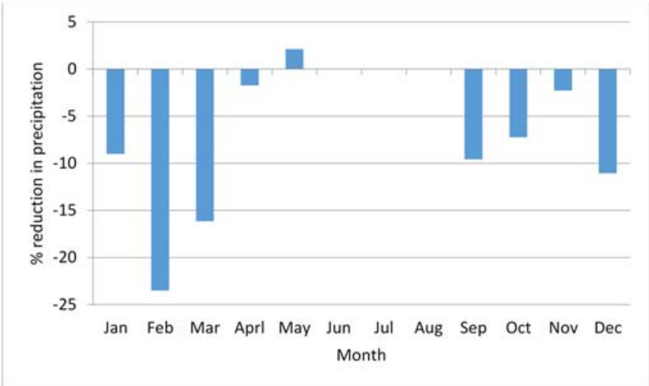

Figure (3): Percent reduction in monthly precipitation during the period (2020-2055) as compared to the baseline period (1970-2005)

Analysis of Historical and Future Drought Conditions

McKee et al. (1993) developed a classification system to describe drought conditions in any region in the world (Table 2). According to this classification, a drought event occurs when the SPI is negative and reaches an intensity at which the SPI is –1.0 or less. The drought event ends when the SPI becomes positive. Postive SPI indicates no drought conditions. The drought duration is the time span of continuous negative SPI. Drought conditions in the selected climatic stations were analyzed using the Standardized Precipitation Index (SPI). The precipitation data for the periods (1970-2005) and (2020-2055) was used to calculate the SPI.

Figure 4 shows the observed SPI time series for Irbid station for 1-month, 3-month, 6-month and 12-month time scales for the period (1970-2005). In addition, Figure 5 shows the future SPI time series for Irbid station under the climate change scenario for the period (2020-2055) for the same time scales. As can be seen from these figures, the number of months with no drought conditions (SPI > 0) is decreased in the future period (2020-2055) under the SRES A2 climate change secenario. The future period (2020-2055) under climate change scenario indicated longer drought duration than the historical period (1970-2005). Near-normal conditions will be increased in the future for Irbid and will be decreased in Baqura and almost no change will occur in Amman region.

Table 2. Drought classess (Mckee et al., 1993)

Drought Class	Symbol	Value
Extremely wet	EW	Greater than 2
Very wet	VE	From 1.5 to 1.99
Moderately wet	MW	From 1.0 to 1.49
Near normal	NN	From -0.99 to 0.99
Moderate drought	MD	From-1.0 to -1.49
Severe drought	SD	From-1.5 to -1.99
Extreme drought	ED	Less than -2

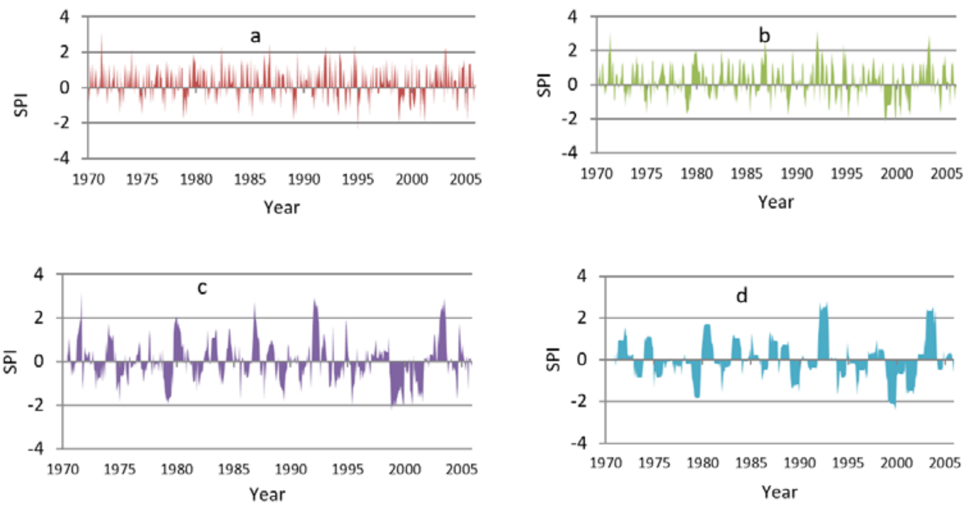

Figure (4): Observed SPI time series for Irbid station for a) 1-month, b) 3-month, c) 6-month and d) 12-month time scales fort he period (1970-2005)

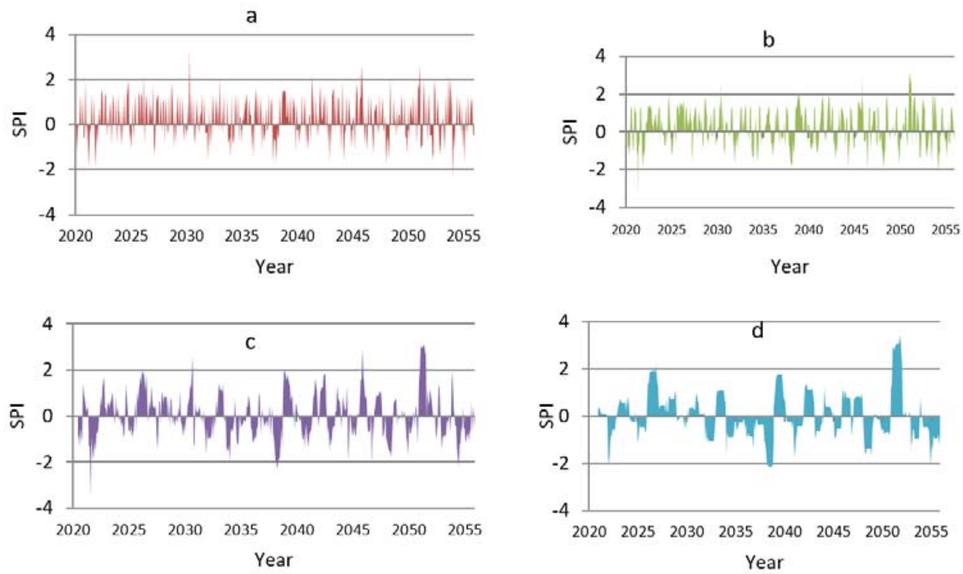

Figure (5): Future SPI time series under A2 climate change scenario for a) 1-month, b) 3-month, c) 6-month and d) 12-month time scales for Irbid station for the period (2020-2055)

The results revealed different changes in drought conditions in the three regions in the future under climate-change scenario. Table 3 indicates that the number of months of moderate/extreme drought conditions will slightly decrease in Irbid region in the future under climate conditions for the period (2020-2055) as compared to the observed period (1970-2005). On the other hand, the number of months of moderate/extreme drought conditions will be significantly increased for Amman region under climate change scenario (SRES A2) for the period (2020-2055) for the time scales of 3, 6 and 12 months. For Baqura region, a slight increase in the months of moderate/extreme drought conditions was predicated for time scales of 1 month and 6 months under future climate change as compared to the observed period. Moreover, a significant decrease was predicted in months of moderate/extreme drought conditions for the time scale of 12 months in Baqura region.

Table 3. Number of months of moderate and severe drought conditions (SPI < -1)

Region	**Base period (1970-2005) and (2020-2055 SERS A2 SPI-1M)**	**Base period (1970-2005) and (2020-2055 SERS A2 SPI-3M)**	**Base period (1970-2005) and (2020-2055 SERS A2 SPI-6M)**	**Base period (1970-2005) and (2020-2055 SERS A2 SPI-1M)**
Irbid	38 (35)	45 (42)	61 (56)	51 (48)
Baqura	36 (38)	42 (40)	61(64)	51 (36)
Amman	33 (26)	41 (50)	45 (65)	59 (62)

The severity and duration of long droughts are projected to increase across the three regions (Table 4), in which the drought duration can exceed 18 months, 21 months and 24 months in Irbid, Amman and Baqoura, respectively. Minimum SPI values indicated severe drought conditions; the results indicated more severe drought conditions in the future under climate change scenario for the period (2020-2055) in all regions as compared to the observed period (1970-2005).

Table 4. Long-drought duration and severity in the three regions

	Observed period (1970-2005)			**Future period (2020-2055) under SRES A2 climate change scenario**		
Region	**Irbid**	**Baqura**	**Amman**	**Irbid**	**Baqura**	**Amman**
# of drought events with durations more than 6 months	16	14	14	19	16	18
Longest duration (months)	16	15	17	15	17	19
Min. SPI (severe condition)	-2.27	-2.35	-2.88	-3.47	-3.27	-2.88

CONCLUSIONS

In this study, observed and future drought characteristics for three clmatic regions in Jordan were evaluated. This study indicated that the climatic regions experienced various moderate and severe droughts events during the period (1970-2005). In the future, under the projected climate change, the three regions will have significant increases in drought severity. The values of outputs of ECHAM5OM model have been used for the calculation of future precipitation time series for the period (2020-2055) under the climate change scenario (SRES A2). The values of observed and future period precipitation at the three climatic regions of Jordan were used for the estimation of SPI for various time scales.

The results revealed that moderate and severe droghts will decrease in the future for Irbid region, while they will increase in the future under climate change for Baqura and Amman regions. Also, the results indicated that future droughts will have longer durations than those of observed period. These results indicate that drought magnitude and severity in the three climatic regions will be negatively impacted under future climate change scenario. Accordingly, the government should plan and develop policies to manage and mitigate these future impacts of droughts in Jordanian climatic regions.

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