Journal of Hydrology: Regional Studies 14 (2017) 83–91

Contents lists available at ScienceDirect

Journal of Hydrology: Regional Studies

journal homepage: www.elsevier.com/locate/ejrh

Multi-site Modeling and Simulation of the Standardized Precipitation Index (SPI) in Jordan

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A R T I C L E I N F O

Keywords:
SPI
Drought analysis
Stochastic modeling and simulation
CARMA

A B S T R A C T

Study region: Five rainfall stations located in the north west mountain region in Jordan.
Study focus: In this study, monthly precipitation data is analyzed using the Standardized Precipitation Index (SPI) at time scale of 12 months (SPI-12). The multi-site Contemporaneous Autoregressive Moving Average (CARMA) model was used to model the SPI-12 data.
New hydrological insight for the region: Simulation experiments with the CARMA (1,1) model reveal that the model performed well in fitting the SPI-12 data. The model was also capable of preserving the cross correlation structure of the observed SPI-12 between the studied sites. Shorter time scale SPI's (such as the 1 and 3 months) were not used due to the fact that Jordan is an arid country and the reliability of SPI's is questionable at the shorter time scales. These results would be important and beneficial in regional studies of water resources in Jordan such as investigating droughts on a regional level rather than on a single site. Also, the results of this study would be important and beneficial for rural areas where no observed data exists.

1. Introduction

The Standardized Precipitation Index (SPI) was developed by McKee et al. (1993) to quantify the precipitation deficit at different time scales. The index only uses precipitation data and ranges between -3 to $+3$. It is based on a standardized probability of a certain amount of precipitation. A negative value indicates a drought condition (below the median value) and a positive value indicates a wet condition (above the median value). A value of zero represents normal conditions (the median) in this case. Table 1 shows the cumulative probabilities of different SPI values. Today, SPI is being widely used in the US (and many other countries around the world) for drought monitoring (Logan et al., 2010). This is, probably, due to the fact that SPI is inheritably normalized which means that a certain SPI value has the same frequency in any location in the world (Logan et al., 2010).

McKee et al. (1993) defined a criteria for classifying droughts based on SPI values as shown in Table 2. Based on this criteria, a drought event occurs any time the SPI is continuously negative and reaches an intensity where the SPI is -1.0 or less and it ends when the SPI becomes positive drought categories for the different SPI values as defined by McKee et al. (1993). McKee et al. (1993) analyzed rainfall data in Colorado and found that these records were in extreme drought category 2.3% of the time; in severe drought 4.4% of the time; in moderate drought 9.2% of the time; and in mild drought category 24% of the time. These values are "expected" and conforms to the values in Table 1.

The time scales used for SPI can be for short time scales (1–3 months) or longer term scale (9–12 months). It can also be for larger scale such as 24 months. The interpretation of the SPI values depends on the time scale it was estimated for. The 1–3 month SPI maybe related closely with the response of the short-term soil moisture conditions to precipitation during that short time scale (World Meteorological Organization, 2012). In contrast, the 6–9 month SPI could be related to the streamflow and the long term (12+

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http://dx.doi.org/10.1016/j.ejrh.2017.11.002
Received 24 June 2017; Received in revised form 30 October 2017; Accepted 2 November 2017

Table 1
Cumulative probabilities of different SPI values (*after* Logan et al., 2010).

SPI	Cumulative Probability
−3	0.0014
−2.5	0.0062
−2	0.0228
−1.5	0.0668
−1	0.1587
−0.5	0.3085
0	0.5000
0.5	0.6915
1	0.8413
1.5	0.9332
2	0.9772
2.5	0.9938
3	0.9986

Table 2
Classification of wet/drought categories according to SPI values (*after* McKee et al., 1993).

SPI	Category
≤ −2	Extreme drought
−1.5 to −2	Severe drought
−1.0 to − 1.5	Moderate drought
−1 to 1	Normal
1–1.5	Moderate wet
1.5–2	Severe wet
≥ 2	Extreme wet

month) SPI could be related to groundwater flow (World Meteorological Organization, 2012).

The short term SPI's can give misleading interpretations when applied in arid areas (World Meteorological Organization, 2012). Zero values could skew the SPI values and as such deviate from the assumption of the normality of SPI. One should be careful in these cases when determining the short term SPI's in arid areas (such as Jordan). Wu et al. (2007) investigated the normality of SPI values in different locations in the USA. In some locations (Kansas and Nebraska), it was found that the short term SPI's (up to 6-week time scale) the SPI's were not normally distributed (Wu et al., 2007).

Paulo et al. (2005) investigated the use of Markov chains and log-linear models for predicting the drought transitional probabilities in Alentejo in the southern region of Portugal. One of the main findings in that paper is that the probability of transitioning from a drought situation to a non-drought situation decreases as the severity of the current drought increases (Paulo et al., 2005).

Shatanawi et al. (2013) used Markov chain and (ARIMA) models for SPI data, of four stations in the Jordan River Basin, for drought characterization and forecasting. It was found that the ARIMA models can be used to forecast long term drought trends in the studied area and the analysis of the Markov transitional probabilities revealed that a drought will likely to persist in that region if the previous two sequences were dry as well (Shatanawi et al., 2013).

Han et al. (2013) used ARMA models to fit and forecast SPI series in the Guanzhong Plain in China and found that the ARMA models can be used effectively for drought forecasting in the studied area. Results indicated that the ARIMA models can be used to forecast short term time scale (1 month) as well as long term (9, 12, and 24 months) time scales (Han et al., 2013).

Multi-site ARMA models have been widely used for modeling hydrologic data at multiple sites. A simpler version of the model, known as CARMA, is also used to model hydrologic data at multiple sites (Salas et al., 2000). Camacho et al. (1985) investigated the identification, estimation and validation of CARMA models. The literature is rich with studies about the CARMA models and their use to model water resources and hydrological systems such as Salas et al. (2000), Rasmussen et al. (1996), Hipel and McLeod (1994), Camacho et al. (1985) and many others.

Simulation experiments using data generation (of synthetic data) is used by hydrologists and water resources managers for many purposes such as reservoir sizing or in reliability studies of water resources systems (Salas et al., 2000). In arid areas, where extended periods of droughts can occur, data generation can be very beneficial in making key management decisions in management of the water resources in these areas (Salas et al., 2000). Once the model has been defined and fitted to the historical data, it can be used to generate synthetic samples from the fitted model. Comparison between historical and generated statistics can be performed for checking whether the fitted model was adequate or not. The main philosophy behind synthetic data generation is that synthetic samples are generated from models that preserve important statistical properties that exist in the historical observed data (Salas et al., 2000). As such, each generated sample is equally likely to occur as the historical sample (Lane and Frevert, 1990).

In this study, a multi-site Contemporaneous Auto Regressive Moving Average (CARMA) model will be used to model the SPI's at 12 month time scale (SPI-12). The performance of the developed models will be investigated using data generation and simulation