Evaluation of drought indices correlation for drought frequency analysis of the Mosul dam watershed

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Abstract. In this paper, drought was evaluated for the Mosul Dam Watershed, Iraq, which is considered one of the most important dams in Iraq. The evaluation of drought was studied using two types of meteorological drought indices, namely Reconnaissance Drought Index (RDI) and Standardized Precipitation Index (SPI), and Hydrological drought index which is Streamflow Drought Index (SDI). Monthly precipitation and air temperature for the period 1979-2013 downloaded from Climate Forecast System Reanalysis (CFSR) were used as weather input data for the RDI and SPI. Streamflow obtained from the gauge station in the study area were used as input data for the SDI. The indices computed by the DrinC software for a 12-month time scale. The results were analysed and the Drought Frequency Patterns (DFPs) were computed for each index. The results showed that potential evapotranspiration plays a major role in causing drought, in addition to precipitation. The RDI gave more dry periods than the other two indices, as it depends on precipitation and potential evapotranspiration. Likewise, all indices are identical in that the period is divided into two parts: the first part, which extends from the beginning of the period 1979 to the end of the nineties 1990s, is considered wet and the second part, which extends to the end of the period 2013, is drier. The Hydrological Drought Index SDI gives a drought of greater severity (Moderate drought for the years 2002, 2003 and 2004) compared to the other two indices.
Keywords: Drought, Mosul Dam Watershed, Drought indices and DFPs.

1. Introduction

Drought is a frequent natural phenomenon associated with a lack of water availability of water resources over a wide geographical area and span over a long period of time [1]. The effects of drought often accumulate slowly over a long period of time that may last for several years, even after the drought has ended, and therefore, it has been described by some authors as a creeping phenomenon [2]. It is difficult to accurately determine the start and end of a drought event. Drought can be either short and continuous for a few months or extended for years before weather conditions return to normal. Meteorological drought is defined as a sustained period for three months or more than the monthly rainfall much lower than the long-term average over several years while the Hydrological drought is described as a deficiency of available water relative to the demand in a given area resulting from a long period of less than average precipitation [3]. Drought analyses based on a single variable (or indicator) can be insufficient because drought phenomena are associated with multiple variables (e.g., rainfall, runoff, and soil moisture). Meteorological drought (a lack of precipitation) may not lead to agricultural drought (a deficit in soil moisture), for example, in tropical regions where average precipitation is relatively high. A complete analysis of drought events requires combined analyses of precipitation conditions, runoff and soil moisture [4]. Frequency, duration and intensity of drought all become functions that depend on the implicitly or explicitly established time scales. No single drought definition or analysis method has emerged that addresses all these issues well. Of the variety of definitions and drought monitoring methods used in the past, by far the most widely used in the United States is the Palmer Drought Index [5] but its weaknesses [6] frequently limit its wise application. For example, the time scale is not defined for the Palmer Index but does inherently exist.

In this paper, the meteorological and hydrological droughts were evaluated for Mosul Dam Watershed, Iraq, by three drought indices, namely: Reconnaissance Drought Index (RDI), Standardized

Precipitation Index (SPI) and Streamflow Drought Index (SDI). These indices are modern and reliable indices that are characterized by their ease and accuracy of results. The Frequency analysis was computed (return period and exceedance probability) to assess the frequency of dry years as well as the frequency of wet years.

2. Methods and Materials

2.1. Methods

The methodology of this paper begins with downloading the precipitation and temperature data from the Climate Forecast System Reanalysis (CFSR) for the period 1979-2013, as this period is only available at CFSR. The data were daily data and converted them to monthly data because the DrinC software version 1.5.73 which is a program used to compute the drought indices SPI, RDI and SDI depends on monthly data (Data can be monthly, annual or seasonal. For monthly data, the software automatically inspects the structure of the file and identifies the position of the data within the spreadsheet, while for annual or seasonal data the user defines the cells from which the loading should start (the National Technical University of Athens Centre for the Assessment of Natural Hazards and Proactive Planning and Lab. of Reclamation Works and Water Resources Management Supervisor: Prof. George Tsakiris Software development: Dimitris Tigkas Research Team: D. Tigkas, H. Vangelis, D. Pangalou) [20]. The SDI computed from streamflow data. Then, DFPS computed. Both the return periods and the exceedance probability of each recurrence of dry years were calculated for each index.

2.2. Meteorological Drought

2.2.1 Standardized Precipitation Index (SPI). SPI is a drought monitoring index created by McKee [19] using a gamma distribution fitting to distribute the station's frequency of total rain. McKee et al developed and computed this index according to periods such as 3, 6, 12, 24, 36 and 48 months. Positive values for this index indicate more than average precipitation and negative values indicate less than average precipitation [7]. The procedure for computing this index is according to [8]. Table 1 illustrates the classification of this index.

Table 1. Classification of meteorological drought based on SPI index value [9].

SPI Values	Classification
2.0 or more	Extremely wet
1.5 to1.99	Very wet
1.0 to 1.49	Moderately wet
0.0 to 0.99	Mild wet
0 to -0.99	Mild drought
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 or less	Extremely dry

2.2.2 Reconnaissance Drought Index (RDI). This index is a new index for defining and assessing drought was first presented at the MEDROPLAN Coordination Meeting [10], while a more comprehensive description was presented in other publications [11][12]. This indicator is based on the ratio between two cumulative amounts of precipitation and the potential evapotranspiration of PET. The procedure for computing this index is according to [7]. Table 2 shows the classifications of RDI.

Table 2. Classification of meteorological drought based on the RDI index value [13].

RDI Values	Classification
2.0 or more	Extremely wet
1.5 to1.99	Very wet
1.0 to 1.49	Moderately wet
0.0 to 0.99	Near normal
0 to -0.99	Mild drought
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 or less	Extremely dry

2.3 Hydrological Drought

2.3.1 Streamflow Drought Index (SDI). Based on SPI development concepts, SDI was developed by Nalbantis and Tsakiris [14] to characterize hydrological drought. Hydrological year from October to September every year. To compute the SDI, the time series of monthly flow volumes is assumed to be Qi, j available where i denotes the hydrological year and j the month during that hydrological year. The procedure for computing the SDI is according to [15]. Table 3 shows the classifications of SDI.

Table 3. Classification of meteorological drought based on the SDI index value [14].

SDI Values	Classification
2.0 or more	Extremely wet
1.5 to1.99	Severely wet
1.0 to 1.49	Moderately wet
0 to 0.99	Mildly wet
0 to -0.99	Mild drought
-1.0 to -1.49	Moderately drought
-1.5 to -1.99	Severe drought
-2 or less	Extreme drought

2.4 Return Period and Exceedance Probability

In this paper, the method adopted for a return period of drought can be considered as the average elapsed time, or the mean interarrival time between two droughts events of a fix or greater severity, according to [16][17][18]. The exceedance probability is calculated from the law (1/return period).

2.5 Study Area and Data Collection

Mosul Dam is considered the most important water storage and control project in Iraq. It plays a vital role in protecting Iraq from the floods and drought risks, in addition to its tangible contribution to supporting the electric power production sector in Iraq. This dam was constructed on the Tigris River at about 60 km to the northwest of Mosul, see Figure 1.

In this paper, two basic types of data are meteorological data and hydrological data. The meteorological data also have two types, namely: precipitation and temperatures. The meteorological data were downloaded from the CFSR. As for the hydrological data, they were taken from one gauging station

within the study area. Figure 2 illustrates the precipitation and potential evapotranspiration, which represents the input data used in the DrinC program to compute the SPI and RDI indices.

Figure 1. Location of Mosul Dam.

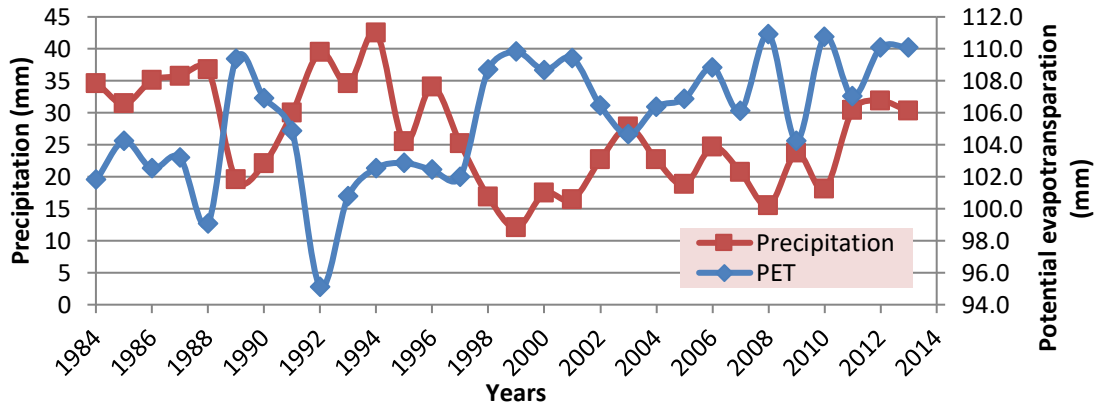

Figure 2. Precipitation for periods 1979-2013 used to compute SPI and RDI, and PET to compute RDI.

3. Results, analysis and Discussion

3.1 Meteorological Drought

After running the DrinC program, the values of the three indices were calculated monthly, and after making the monthly calculations, the annual calculations found as the result of their average because they covered the annual precipitations of the stations during a year. The results were as follows:

3.1.1 Computation of SPI.

This index is easy and simple because it depends on one factor, which is precipitation. The results indicated that the region is more wet than dry because the wet years are nineteen years and are divided

into three periods: 1979-1988, 1991-1996 and 2011-2013 and all of these years are mild wet except for the year 1988 that was moderate wet. As for the remaining periods 1989-1990 and 1997-2010, all were dry years, except for the year 1999, which was recorded as moderate drought. As is evident from these results, the end of the nineties and the beginning of the 2000s is a dry period compared to the previous period, and by referring to Figure 2, it is clear that the amount of precipitation decreasing during this period. Figure 3 shows the SPI values for the period 1979-2013. Figure 4 shows the number of recurrences of successive dry years, as well as the probability of each recurrence. As is evident from this Figure, the one dry year did not occur and the two consecutive dry years are the most frequent, which occurs with periods of recurrence every five years with an exceedance probability of 20%, followed by a recurrence of the three to seven consecutive dry years that occur every ten years with the exceedance probability of 10%, and then the rest of the recurrences of the dry years from eight consecutive years to eleven years successive dry occurrence every twenty-six years with the exceedance probability of 4%.

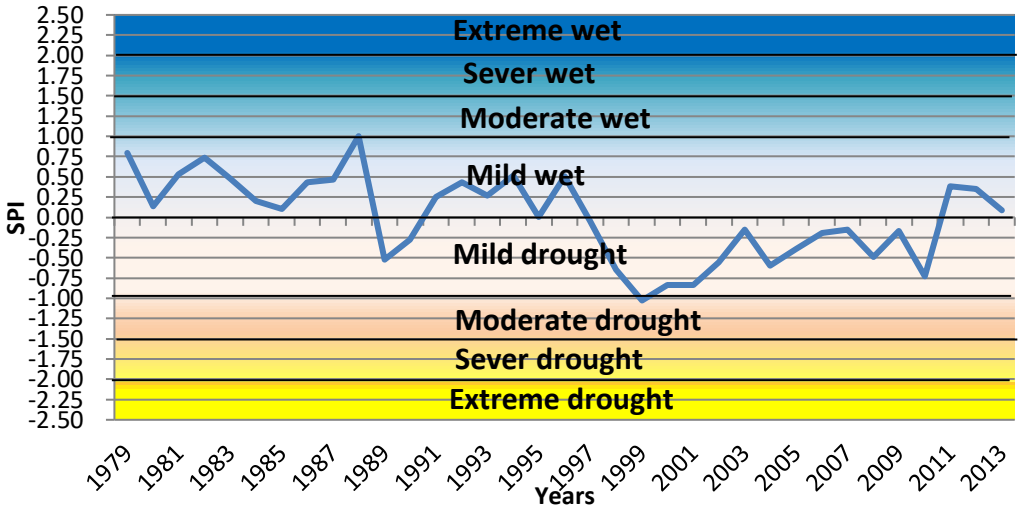

Figure 3. Values of SPI for the Period 1979-2013.

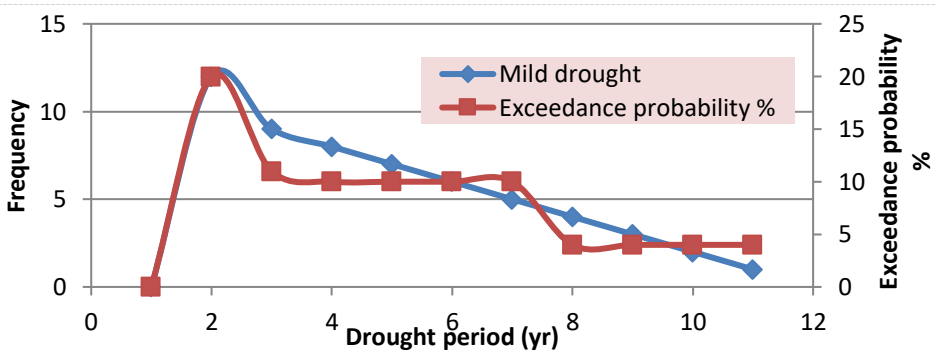

Figure 4. SPI drought (Mild to extreme drought) successive reoccurrence interval and exceedance probability versus frequency, for the period 1979-2013.

3.1.2 Computation of RDI.

The results of this index are opposite to the results of SPI, as the dry years are more than the wet years, where the dry years represent twenty years, which are concentrated in the period 1997-2013 which is

mildly drought except the years 2009, 2011 and 2012 which is a wet year. The wet years are fifteen years and are concentrated during the period 1979-1996 which is recorded near normal; except the years 1984, 1985, 1989, 1990 and 1991 which is a mild drought. Figure 5 shows the RDI values during these periods. But this index is consistent with the SPI in that the end of the nineties and the beginning of the 2000s is a dry period, that the period before it is wetter, and that the year 1988 is the wettest year, which was recorded with both indices moderate wet. The one dry year is repeated eleven times during the period 1979-2013, and it occurs in periods of recurrence every eleven years. As for the recurrence of the dry years for successive years, the recurrence of two consecutive dry years is the most frequent which has happened every five years. After the two consecutive two dry years, the recurrence of three consecutive dry years is followed and occurs with a return period of seven years. Twelve consecutive dry years is the biggest recurrence. These results are shown in Figure 6 with the exceedance probability of each recurrence. This index is more reliable than the one before it because it depends on two factors and not one factor, namely precipitation and evapotranspiration.

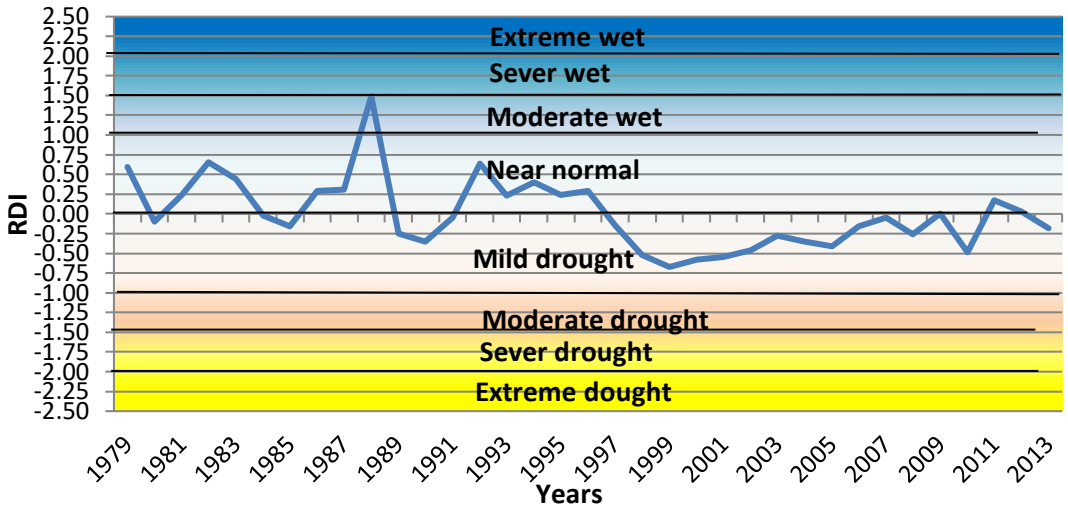

Figure 5. Values of RDI for the period 1979-2013.

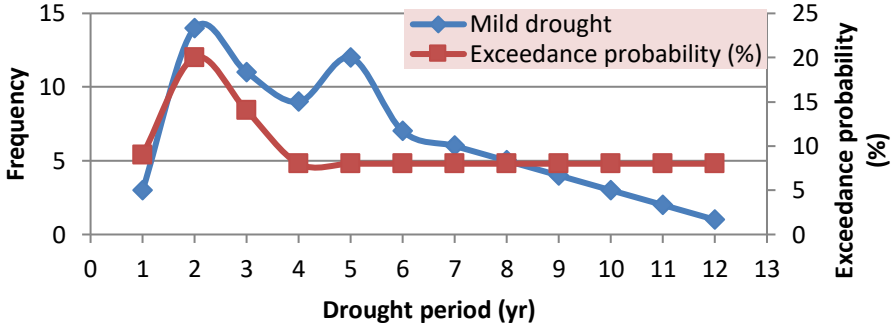

Figure 6. RDI drought (Mild to extreme drought) successive reoccurrence interval and exceedance probability versus frequency, for the period 1979-2013.

3.2 Hydrological Drought

3.2.1 Computation of SDI. The SDI index assesses hydrological drought and is based only on streamflow. The results of this index were identical with the SPI index in the number of wet years, which represents nineteen years, and dry years, sixteen years, but with an intensity relatively higher than the

intensity of drought according to the SPI. As the dry years are concentrated during the period 1998-2013, in which the years 2002, 2003 and 2004 are recorded as moderate drought. While the period 1979-1997 was a wet period, the year recorded mild wet and the year 1991 recorded a severe wet, except the years 1982, 1986, 1988, 1989, 1992, 1994 and 1996 which is a mild drought. As for the recurrence of consecutive dry years, moderate drought recurs for two and three consecutive years in a row, and it occurs with recurrence periods every sixteen years. As for the one-year moderate drought, it occurs every seventeen years, and it occurred only once during the period 1979-2013. As for the recurrence of the successive dry years of the mild drought, it was also repeated for two and three years in a row, with return periods of seven and eleven years, respectively. As for the one year, it occurred five times during the entire period, with recurring periods every five years. Figures 7 and 8 illustrate the values of SDI and Drought (Mild to extreme drought) successive reoccurrence interval and the exceedance probability versus frequency, for the period 1979-2013.

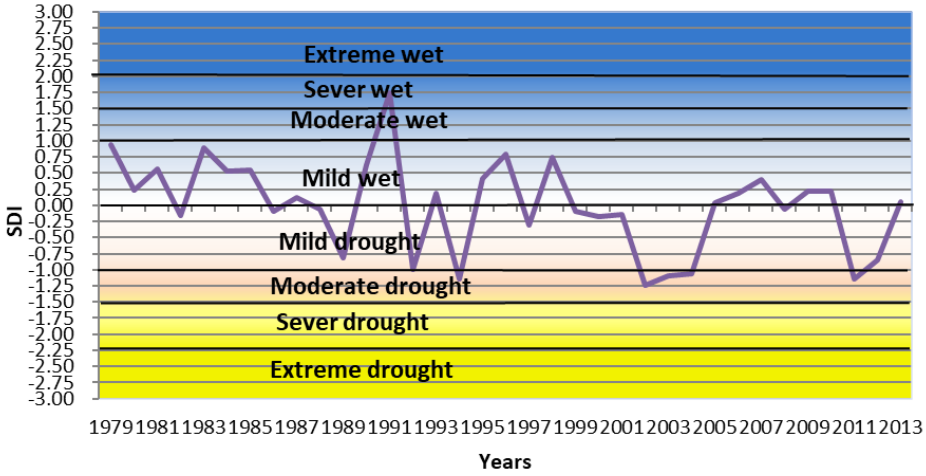

Figure 7. Values of SDI for the period 1979-2013.

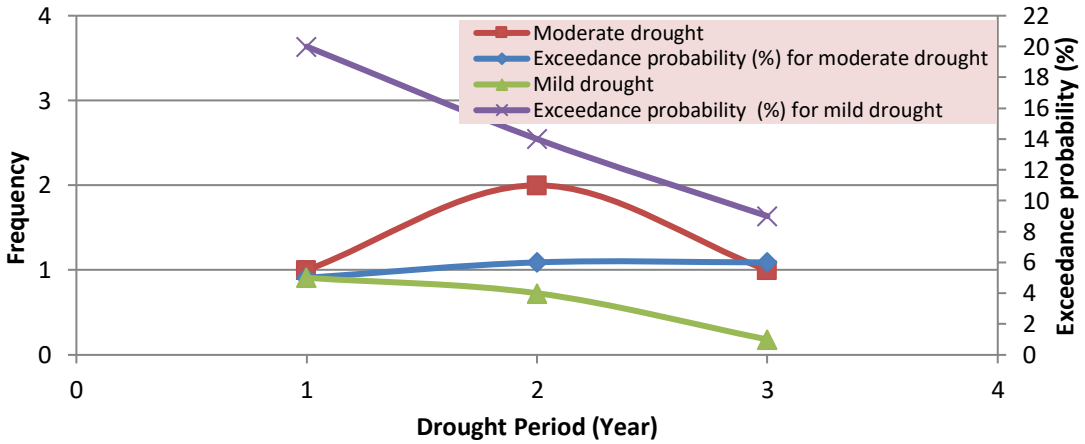

Figure 8. SDI drought (Mild to extreme drought) successive reoccurrence interval and exceedance probability versus frequency, for the period 1979-2013.

From the analysis, the recently proposed RDI has many advantages and more reliable than the widely used indices for assessing meteorological droughts. The RDI is expected to be a more sensitive index than those related only to precipitation. This matches the researchers' studies [7][12][19].

4. Conclusion

This paper provided monitoring and evaluation of droughts in the Mosul Dam Watershed, Iraq, for the period 1979-2013, for this purpose, the SPI, RDI and SDI drought indices were computed, as well as the return period and exceedance probability. The main conclusions of this study were: all indices are agreed that the period from 1979 to the end of the 1990s is a rather wet period, while the period from the end of the 1990s to 2013 is drier. The SPI and SDI indices are identical in the number of dry years and wet years, but the SDI index has severely slightly higher than the SPI index. In contrast to the RDI, its results gave more dry years than wet years. All indices are identical in that the two consecutive dry years are the most frequent during the whole period and the probability of occurrence is greater than the rest of the recurrences. While the one-year recurrence very little during the whole period while the SPI index did not occur in it. Potential evapotranspiration plays a major role in causing drought, so the RDI is more reliable than the other two indicators because it depends on Potential evapotranspiration and precipitation.

As for future work that should be taken into consideration as a result of the analysis and discussion of the results of this paper, it is to use other indices to assess drought, namely: Agricultural Standardised Precipitation Index (aSPI), Effective Reconnaissance Drought Index (eRDI) and Precipitation Deciles (PD).

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