

Identification of dry and wet 6 months' period in eastern Slovakia using indices

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Abstract. In the paper we evaluated dry and wet 6 months' periods, which reflect changes in water resources of the country. We assessed Standardized Precipitation Index (SPI), Standardized Evapotranspiration Index (SPEI), Streamflow Drought Index (SDI), Reconnaissance Drought Index (RDI). The time period was 1960 - 2015 and the study area includes eastern Slovakia – selected water and climatic stations. The results indicate dry periods and wet periods. The results of work are presented in the table for separate evaluated indices.

1 Introduction

Earth's climate is changing. Temperatures are rising, snow and precipitation patterns are changing, and extreme climatic events - such as heavy rains and increasing temperatures are occurring. Climate change refers to major climate parameters (such as temperature or precipitation) that change during the longer periods. Natural factors have caused climate change during previous periods of Earth's history, but human activities are primarily due to the changes that are currently observed [1-3].

Extreme events such as floods and droughts are the most serious and the most natural risks associated with climate change. Drought is one of the most serious threats to people having adverse effects on the economy, industry [4]. Defining a drought is complicated depending on the area where it occurs, the length of time in which climate zone is perceived the observed area and other various aspects. The simplest definition of drought is a phenomenon that occurs during periods of subnormal precipitation from a duration of several days to several months [5]. Compared to the floods, drought slowly develops and is only acknowledged when changes in the environment begin to be felt and people begin to feel them. From this reason, it is difficult to determine when the drought started and when it ended. Initially, it occurs as subnormal precipitation and, for a long time, drought has an impact on the hydrological cycle. Evapotranspiration is mainly influenced by temperature. Temperature is one of the main factors affecting the availability of water and has a consequent effect on the occurrence of drought and the nature of drought [6-7].

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Drought indices are based on hydrological and meteorological parameters. The most commonly used indices droughts include the Palmer Index (PDSI) and the Standardized Precipitation Index (SPI) [8].

In this paper we evaluated the dry and wet periods by the drought indices: Standardized Precipitation Index (SPI), Standardized Evapotranspiration Index (SPEI), Reconnaissance Drought Index (RDI), Streamflow Drought Index (SDI). These indices differ in input parameters. The data were provided by the Slovak Hydrometeorological Institute, Košice Regional Office.

2 Material and Methods

As we mentioned, we have identified dry and wet seasons using SPI, SPEI, RDI and SDI. The evaluated indexes have different input parameters.

Negative values of indices mean dry period and positive values of indices mean wet period, while the intensity is graded in individual degrees.

Table 1. Classification value indices [2].

Period	Value of index
Extremely wet	2.0 and more
Very wet	1.5 to 1.99
Moderately wet	1 to 1.49
Near normal	-0.99 to 0.99
Moderately dry	-1 to -1.49
Severely dry	-1.5 to - 1.99
Extremely dry	-2 and less

The Standardized Precipitation Index (SPI) uses precipitation records. SPIs can only be calculated on the basis of a minimum time series of 20 years, but ideally is, if the time series are 30 years old, even if data are missing. Time steps that can be evaluated are from 1 month to 48 months [7].

The Standardized Evapotranspiration Index (SPEI) uses the similar basis, but in addition to precipitation, it uses air temperature to calculate evapotranspiration [7]. The Streamflow Drought Index (SDI) uses input data of water discharge and SPI-related normalization methods [8].

The Reconnaissance Drought Index (RDI) contains a simplified water balance equation that includes precipitation and potential evapotranspiration. It has three outputs: initial value, normalized value and standardized value. We used a standardized value in this contribution. The standardized value of RDI is similar in nature to SPI and can be compared [9].

SPI, SDI and SPEI were calculated using Drin software. In addition, the software includes a module for estimating the potential evapotranspiration of potential evapotranspiration (PET) based on temperature for methods that are useful for calculating RDI. The software can be used in a variety of applications such as monitoring, spatial drought assessment, climatic and drought scenarios [8].

We calculated the SPEI using the statistical software RGui. It is a GNU project (Linux operating system) that is similar to the S language and environment.

3 Data and study area

The water and climatological stations I evaluated are located in eastern Slovakia. The stations Poprad, Svit, Chmeľnica and Červený Kláštor are located in the Poprad and Dunajec basins on the Poprad River. The basin of Poprad and Dunajec is located in the north of eastern Slovakia. The stations Švedlár, Mníšek nad Hnilcom and Stratená are located in the catchment area Hornád on the river Hnilec. In the Bodrog basin there are stations Kamenica nad Cirochou, Humenne, Krasny Brod, Tisinec-Stropkov and Streda nad Bodrogom. Košice weather station is located in the Hornád basin. The latitude and longitude of the stations are shown in Table 2.

Table 2. Localization of assessment stations.

Station	Latitude	Longitude
Poprad	49°3'41.18"	20°17'52.73"
Svit	49°3'36.5"	20°12'25.02"
Chmeľnica	49° 17' 60.0"	20° 43' 59.99"
Červený Kláštor	49° 23' 30.48"	20° 24' 19.08"
Stratená	48°52'12.72"	20°22'38.64"
Mníšek nad Hnilcom	48° 48' 15.12"	20° 48' 16.92"
Švedlár	48° 48' 59.99"	20° 42' 59.99"
Humenné	48°56'13.45"	21°54'58.5"
Kamenica nad Cirochou	48° 55' 59.99"	22° 00' 0.00"
Krásny Brod	49° 14' 23"	21° 53' 54"
Tisinec-Stropkov	49°12'7.6"	21°39'7.78"
Streda nad Bodrogom	48°23'25.37"	21°45'9.97"
Košice	48°42'50.22"	21°15'29.09"

Table 3 shows the input values, the evaluation period and the average annual values of the indicators for the evaluation period from the data available to me. Data provided by SHMI were average monthly values of climatological and hydrological variables.

Table 3. Input data and evaluated period.

Station	Input variables	Assessed period	Yearly average values
Poprad	Precipitation	1960-2014	601,1 [mm]
	Temperature	1960-2014	6,15 [°C]
Svit	Streamflow	1965-2015	1,29 [m ³ /s]
Chmeľnica	Streamflow	1960-2015	15,1[m ³ /s]
	Precipitation	1980-2010	771[mm]
Červený Kláštor	Temperature	1961-2014	6,34 [°C]
Stratená	Streamflow	1960-2015	1,1 [m ³ /s]
Mníšek nad Hnilcom	Precipitation	1980-2010	710 [mm]
Švedlár	Temperature	1961-2014	6,56 [°C]
Humenné	Streamflow	1968-2015	13,2 [m ³ /s]

	Precipitation	1980-2014	729,1[mm]
Kamenica nad Cirochou	Temperature	1960-2014	8,7 [°C]
Krásny Brod	Streamflow	1960-2015	2,05 [m ³ /s]
	Precipitation	1986-2010	831,7 [mm]
Tisinec-Stropkov	Temperature	1963-2010	8,14 [°C]
Streda nad Bodrogom	Precipitation	1980-2010	605,3 [mm]
	Streamflow	1960-2015	110 [m ³ /s]
Košice	Temperature	1960-2014	9,1 [°C]

The input data, as was mentioned, were provided by the Slovak Hydrometeorological Institute.

4 Results

The results from the assessment is provided in the next Tables.

Two extremely dry seasons were recorded in Poprad and Svit in the observed time series during the years 1978-1979 and 13 very dry seasons in 1981-1982 were recorded as is seen from Table 4.

Table 4. Assessment of 6 monthly indices in Poprad/Svit drought seasons.

Poprad/Svit				
Indices	SDI		SPI	
Season	October - March	April - September	October - March	April - September
Extremely dry	1978-1979 1981-1982	1978-1979 1981-1982		
Severely dry	1991-1992 1982-1983	1991-1992 1982-1983	1981-1982	
Indices	RDI		SPEI	
Extremely dry	1973-1974 1983-1984			
Severely dry	1971-1972 1972-1973 1977-1978 2001-2002	1981-1982 1985-1986	1986-1987	1981-1982 2002-2003 2011-2012

Periods that are bold are repeated in multiple indexes.

In Table 5, extremely humid and very humid periods are evaluated. There were 5 extremely wet seasons and 11 very wet seasons.

Table 5. Assessments of 6 monthly indices in Poprad/Svit wet seasons.

Poprad/Svit				
Indices	SDI		SPI	
Season	October - March	April - September	October - March	April - September

Extremely wet	2000-2001	2000-2001	1974-1975	1974-1975
Severely wet	1971-1972 1999-2000	1971-1972 1999-2000	1964-1965 1976-1977 2012-2013	1962-1963 1964-1965
Indices	RDI		SPEI	
Extremely wet	1974-1975	1971-1972 2009-2010	1974-1975	
Severely wet	1962-1963 1964-1965	2000-2001 2013-2014	2010-2011	1969-1970 1971-1972 2009-2010

There were 5 extreme drought periods observed at the stations Streda nad Bodrogom and Kosice, as is seen in Table 6.

Table 6. Assessments of 6 monthly indices in Streda nad Bodrogom/Košice dry seasons.

Streda nad Bodrogom/Košice				
Indices	SDI		SPI	
Season	October - March	April - September	October - March	April - September
Extremely dry	1963-1964	1960-1961		
Severely dry	1972-1973 1989-1990	2006-2007	1972-1973 1976-1977 1983-1984	
Indices	RDI		SPEI	
Extremely dry	1986-1987	1991-1992 2002-2003		
Severely dry	1996-1997 1997-1998	1992-1993 1993-1994 2001-2002 2008-2009		2002-2003

In bold, the periods that have been repeated are highlighted.

Seven extremely humid seasons and seven very humid seasons were occurring in Streda nad Bodrogom and Košice, see Table 7.

Table 7. Assessments of 6 monthly indices in Streda nad Bodrogom/Košice wet seasons.

Streda nad Bodrogom/Košice				
Indices	SDI		SPI	
Season	October - March	April - September	October - March	April - September
Extremely wet	1974-1975	1979-1980 2009-2010	1990-1991	1990-1991
Severely wet	1966-1967 1998-1999	1984-1985 2004-2005		

		2005-2006		
Indices	RDI		SPEI	
Extremely wet	1981-1982 1999-2000			2009-2010
Severely wet	1998-1999 2009-2010		1979-1980	1979-1980

One extremely dry period was recorded in Humenné and Kamenica nad Cirochou, and only in the SDI index. Very dry periods occurred in seven cases, see Table 8.

Table 8. Assessments of 6 monthly indices in Humenné/Kamenica nad Cirochou dry seasons.

Humenné/Kamenica nad Cirochou				
Indices	SDI		SPI	
Season	October - March	April - September	October - March	April - September
Extremely dry	1976-1977	1976-1977		
Severely dry	1988-1989 2006-2007	1988-1989 2006-2007	1972-1973 1973-1974 1982-1983	
Indices	RDI		SPEI	
Extremely dry				
Severely dry	1984-1985	2002-2003 2006-2007	1984-1985	2002-2003 2006-2007

Two extremely wet seasons were recorded in Humenné and Kamenica nad Cirochou, 1990-1991 in the SPI index and 2009-2010 in the SPEI index. Very wet periods occurred in the SDI, RDI and SPEI index, see Table 9.

Table 9. Assessments of 6 monthly indices in Humenné/Kamenica nad Cirochou wet seasons.

Humenné/Kamenica nad Cirochou				
Indices	SDI		SPI	
Season	October - March	April - September	October - March	April - September
Extremely wet			1990-1991	1990-1991
Severely wet	1967-1968 1969-1970 1991-1992	1967-1968 1969-1970 1991-1992		
Indices	RDI		SPEI	
Extremely wet				2009-2010
Severely wet	1980-1981 1985-1986 1998-1999 1999-2000		2002-2003 2008-2009 2009-2010	

Four extremely dry periods in SDI and RDI were recorded in Krásny Brod and Tisinec. Very dry periods were recorded for ten cases and occurred in all observation indices, see Table 10.

Table 10. Assessments of 6 monthly indices in Krásny Brod/Tisinec dry seasons.

Krásny Brod/Tisinec				
Indices	SDI		SPI	
Season	October - March	April - September	October - March	April - September
Extremely dry	1983-1984			
Severely dry	1962-1963 1995-1996	2006-2007 2014-2015	1963-1964 1969-1970	1963-1964 1969-1970
Indices	RDI		SPEI	
Extremely dry		1993-1994 1999-2000 2002-2003		
Severely dry		1987-1988 1990-1991 1994-1995 1998-1999		1988-1989

Four extremely wet seasons were recorded in Krásny Brod and Tisinec in the SDI and RDI indices. Very dry periods were recorded in ten and occurred in SDI, SPI, RDI and SPEI, see Table 11.

Table 11. Assessments of 6 monthly indices in Krásny Brod/Tisinec wet seasons.

Krásny Brod/Tisinec				
Indices	SDI		SPI	
Season	October - March	April - September	October - March	April - September
Extremely wet		1979-1980 2009-2010		
Severely wet	1978-1979 1999-2000	2004-2005	1984-1985	1984-1985
Indices	RDI		SPEI	
Extremely wet	1991-1992 1994-1995			
Severely wet	1986-1987 1987-1988 1992-1993 1999-2000	2009-2010	2009-2010	1990-1991

Periods that are highlighted in bold appear multiple times.

Three extremely dry periods in the SDI and RDI index were found in Chmeľnica and Červený Kláštor. Very dry periods were found in ten cases see Table 12.

Table 12. Assessments of 6 monthly indices in Chmel'nica/Červený Kláštor dry seasons.

Chmel'nica/Červený kláštor				
Indices	SDI		SPI	
Season	October - March	April - September	October - March	April - September
Extremely dry	1977-1978	1977-1978		
Severely dry	1967-1968 2005-2006	1967-1968 2005-2006	1960-1961 1962-1963	1960-1961
Indices	RDI		SPEI	
Extremely dry		1980-1981 1986-1987		
Severely dry		1987-1988 1992-1993 1993-1994 2002-2003		1979-1980 1984-1985

In Chmel'nica and Červený Kláštor were recorded two extremely wet seasons. The period 1993-1994 occurred in the SDI index and the period 1999-2000 occurred in the RDI index. In the SPI index, an extremely wet and very wet period was not found. Three very wet periods were recorded in the SDI index, five very wet periods occurred in the RDI index, and two wet periods were recorded in the SPEI index, see Table 13.

Table 13. Assessments of 6 monthly indices in Chmel'nica/Červený Kláštor wet seasons.

Chmel'nica/Červený kláštor				
Indices	SDI		SPI	
Season	October - March	April - September	October - March	April - September
Extremely wet	1993-1994	1993-1994		
Severely wet	1960-1961 1968-1969 1970-1971	1960-1961 1968-1969 1970-1971		
Indices	RDI		SPEI	
Extremely wet	1999-2000			
Severely wet	1982-1983 1985-1986 1991-1992 1994-1995 2009-2010			1999-2000 2002-2003

At the evaluated stations Stratená, Švedlár and Mníšek nad Hnilcom, one extremely dry period was found in the SDI index and three extremely dry periods were recorded in the RDI index. Very dry periods occurred in eight cases, see Table 14.

Table 14. Assessments 6 monthly indices Stratená/Švedlár/Mníšek nad Hnilcom dry season.

Stratená/Švedlár/Mníšek nad Hnilcom				
Indices	SDI		SPI	
Season	October - March	April - September	October - March	April - September
Extremely dry		1992-1993		
Severely dry	1983-1984 1986-1987	1960-1961 2002-2003	1981-1982 1982-1983	
Indices	RDI		SPEI	
Extremely dry	1983-1984 2001-2002	1985-1986		
Severely dry	1989-1990	1980-1981 1981-1982 1986-1987 1992-1993 2002-2003		2002-2003

Eight extreme wet seasons and eight very wet seasons were recorded in Stratená, Švedlár and Mníšek nad Hnilcom in SDI, SPI and RDI, see Table 15.

Table 15. Assessments of 6 monthly indices in Stratená/Švedlár/Mníšek nad Hnilcom wet seasons.

Stratená/Švedlár/Mníšek nad Hnilcom				
Indices	SDI		SPI	
Season	October - March	April - September	October - March	April - September
Extremely wet	1974-1975 1976-1977 2010-2011	1964-1965 1971-1972	1989-1990	
Severely wet	1964-1965 1980-1981	1977-1978 2009-2010 2012-2013	1985-1986	1985-1986
Indices	RDI		SPEI	
Extremely wet	1982-1983 2009-2010	2009-2010	2009-2010	2009-2010
Severely wet	1998-1999 2008-2009			

Periods that are highlighted in a bold font colour appear in multiple indexes.

5 Conclusions

The contribution was focused on the evaluation of dry and wet periods using SDI, SPI, RDI and SPEI drought indices in time series 1960-2015 in a time step of 6 months. Time step 6 months reflects changes in water accumulation in water reservoirs. The results of the evaluated sites show alternation of dry and wet periods. Extremely wet seasons and very dry seasons that occurred most frequently at the monitored stations were 1960-1961, 1963-

1964, 1967-1968, 1969-1970, 1976-1977, 1977-1978, 1978-1979, 1981-1982, 1983- 1984, 1984-1985, 1986-1987, 1988-1989, 1992-1993, 2002-2003,2005-2006, 2006-2007. Extremely wet seasons and the most wet seasons were: 1960-1961, 1962-1963, 1964-1965, 1968-1969, 1970-1971, 1971-1972, 1974-1975, 1979-1980, 1984-1985, 1985-1986, 1990-1991, 1993-1994, 1998-1999, 1999-2000, 2000-2001, 2009-2010. As can be seen in the hydrological years 1960-1961 and 1984-1985, the 6-month wet period alternated with the dry 6-month period.

As a result, it is possible to propose adaptation measures for better water management in the evaluated areas. Adaptation measures may be an overestimation of water levels in river basins in the dry season and water retention in the wet season.

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