Identification of dry and wet years in eastern Slovakia using indices

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Abstract. The aim of the paper was to evaluate dry and wet periods in selected climatic stations in eastern Slovakia using the drought indices. We evaluated drought occurrence using the following indexes: standardized precipitation index (SPI), streamflow drought index (SDI), drought reconnaissance index (RDI) and standardized evapotranspiration index (SPEI) in a 12-month step over the period 1960-2015. The evaluation of the results showed alternation of wet and dry periods. The result of the work is identification of the dry and wet years according the separate indexes during the evaluated period.

1. Introduction
Drought is increasingly frequent in temperate climates [1]. Drought as a natural phenomenon is an extreme phenomenon whose perceptions threaten not only nature and the landscape, but also society. The primary consequence of drought is the lack of precipitation and, consequently, the reduced runoff of surface waters in the river basins. Drought can negatively affect agriculture and industry, drinking water supply, drying of small streams and springs, electricity production [2]. Assessing the occurrence of dry and wet periods and monitoring its consequences is important in terms of adaptation measures to this natural phenomenon [3].
Drought is difficult to define on the basis of hydrometeorological variables and socio-economic factors, as well as different water demand in different regions of the world. Li et al. [4] stated that very different views on the definition of drought are one of the main obstacles in assessing drought. In assessing drought, a distinction must be made between conceptual and operational definitions. The conceptual definition of drought is determined in relative terms (eg drought is a long dry period). The operational definition of drought attempts to identify the onset, severity and end of drought. The general definition of drought can be used to analyse drought frequency, drought severity and duration for a given period. Drought definitions can therefore be divided into different categories: hydrological, meteorological, agricultural and socio-economic [5]. Many drought indices have been developed to assess drought, each with its strengths and weaknesses.

2. Materials and methods
We evaluated the dry and wet periods using the SPI, SPEI, RDI and SDI indices. These indices differ in input parameters. The data were provided by the Slovak Hydrometeorological Institute, Košice Regional Center.
2.1 Drought indices
Positive index values mean wet periods, negative values mean dry periods, while the intensity is graduated in individual degrees (Table 1).

| Period            | Value of index |
|-------------------|----------------|
| Extremely wet     | 2.0 +          |
| 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    |

2.2 Standardized precipitation index (SPI)
SPI uses historical rainfall records for any location to determine the probability of a rainfall event that can be calculated in any number of time zones ranging from 1 month to 48 months or longer. SPIs can only be calculated based on a minimum time series of 20 years, but ideally, time series should have a minimum of 30 years of data, even if there are missing data [2].

2.3 Standardized evapotranspiration index (SPEI)
As a relatively new drought index, SPEI uses the SPI basis, but includes a temperature component, which allows the index to take into account the effect of temperature on drought through a basic water balance calculation. The SPEI has an intensity scale in which both positive and negative values identifying wet and dry events are calculated. It can be calculated for time steps from 1 month to 48 months or more. Monthly updates allow SPEI to function functionally, and the longer the time series of available data, the more robust the results will be [7].

2.4 Streamflow drought index (SDI)
Developed using monthly water flow values and SPI-related normalization methods. It can be calculated for both observed and forecasted data, providing a perspective of high and low flow rates related to drought and floods. Input parameters: water flow data in daily or monthly time range [7].

2.5 Drought reconnaissance index (RDI)
The drought index contains a simplified water balance equation that includes precipitation and potential evapotranspiration. It has three outputs: initial value, normalized value and standardized value. The standardized value of RDI is similar in nature to SPI and can be directly compared to it. RDI is more representative than SPI because it considers full water balance instead of rainfall alone. Input parameters: monthly temperature and precipitation values [7].

2.6 Software Drinc
The program aims to present the overall calculation and implementation of the software together with the use of different approaches to drought analysis. DrinC can be used to calculate RDI reclamation indices, SDI flow index and the commonly known standardized SPI precipitation index. In addition, the software includes a module for estimating the potential evapotranspiration of PET based on temperature for methods that are useful for calculating RDI. The software can be used in a variety of applications such as drought monitoring, drought assessment, climate and drought scenarios, etc. [8].

2.7 RGui software
Is software for calculating SPEI. R is the language and background for statistical computing and graphics.
3. Assessment climatology and water meter station

Assessment water and climatological stations are located in eastern Slovakia. The position of the assessment stations latitude and longitude is described in the Table 2.

| 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' 00.00" |
| 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 describes input values and evaluated periods.

| Station                  | Assessed variables | Assessed period |
|--------------------------|--------------------|-----------------|
| Poprad                   | Precipitation      | 1960-2014       |
|                          | Temperature        | 1960-2014       |
| Svit                     | Streamflow         | 1965-2015       |
|                          | Streamflow         | 1960-2015       |
| Chmeľnica                | Precipitation      | 1980-2010       |
| Červený Kláštor          | Temperature        | 1961-2014       |
| Stratená                 | Streamflow         | 1960-2015       |
| Mníšek nad Hnilcom       | Precipitation      | 1980-2010       |
| Švedlár                  | Temperature        | 1961-2014       |
|                          | Streamflow         | 1968-2015       |
| Humenné                  | Precipitation      | 1980-2014       |
| Kamenica nad Cirochou    | Temperature        | 1960-2014       |
|                          | Streamflow         | 1960-2015       |
| Krásny Brod              | Precipitation      | 1986-2010       |
| Tisinec-Stropkov         | Temperature        | 1963-2010       |
| Streda nad Bodrogom      | Precipitation      | 1980-2010       |
|                          | Streamflow         | 1960-2015       |
| Košice                   | Temperature        | 1960-2014       |

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

4. Results

4.1 Assessment of 12 monthly index
At the stations Streda nad Bodrogom and Košice there were two extremely dry periods in the RDI index 1989-1990, 1990-1991. In the SDI, SPI and SPEI indices there were no extremely dry periods. Severely dry periods were recorded in the SDI index 1962-1963, 1962-1963, 1971-1972, 1989-1990, 2013-2014. In the SPI index there were two very dry periods 1972-1973 and 1983-1984 (Table 4). In Krásny Brod and Tisinec extremely dry periods were recorded in SPI in 1963-1964, 1969-1970 and RDI index of the period 1993-1994, 2002-2003. There were no extreme dry periods in SDI and SPEI. Severely dry periods were recorded in the SDI index 1960-1963 and in RDI 1990-1991, 1996-1997 (Table 4). In Humenné and Kamenica nad Cirochou extremely dry periods were recorded in RDI of the period 1979-1980, 2005-2006. There were no extreme dry periods in other indices. Severely dry periods were recorded in SDI 1995-1996 and in RDI 2001-2002, 2002-2003, 2006-2007 (Table 4). Extremely dry seasons occurred in Chmeľnica and Červený Kláštor in SDI 2005-2006 and SPI 1965-1966. Severely dry seasons were recorded in SDI 1975-1976, SPI 1972-1973 and SPEI 1981-1982 (Table 4). In Stratená, Švedlár and Mníšek nad Hnilcom, one extremely dry period was recorded in SDI 1992-1993. Severely dry periods occurred in the SDI index 2011-2012, in SPI 1965-1966 and in SPEI 1985-1986 (Table 4).

**Table 4.** Assessment of 12 monthly index for all station for dry season.

| Station                        | Season    | SDI        | SPI        | RDI        | SPEI       |
|-------------------------------|-----------|------------|------------|------------|------------|
| Svit/Poprad                   | Severely dry | 1962-1963  | 1963-1964  | 1963-1964  | 1981-1982  |
|                               |           | 1963-1964  | 1981-1982  | 1985-1986  | 1985-1986  |
|                               |           | 1971-1973  | 1972-1973  | 2011-2012  | 2011-2012  |
|                               |           | 1989-1990  | 1985-1986  | 1985-1986  | 1985-1986  |
|                               |           | 2013-2015  | 2011-2012  | 2011-2012  | 2011-2012  |
| Streda nad Bodrogom/Košice    | Severely dry | 1960-1961  | 1961-1962  | 1962-1963  | 1969-1970  |
|                               |           | 1962-1963  | 1963-1964  | 1993-1994  | 1981-1982  |
|                               |           | 1963-1964  | 1990-1991  | 2001-2002  | 1981-1982  |
|                               |           | 2004-2005  | 2005-2006  | 2006-2007  | 1981-1982  |
| Humenné/Kamenica nad Cirochou | Severely dry | 1975-1976  | 1972-1973  | 1990-1991  | 1981-1982  |
|                               |           | 1969-1970  | 2002-2003  | 1981-1982  | 1981-1982  |
|                               |           | 1965-1966  | 1985-1986  | 1985-1986  | 1985-1986  |
|                               |           | 2005-2006  | 1985-1986  | 1985-1986  | 1985-1986  |
|                               |           | 1965-1966  | 1985-1986  | 1985-1986  | 1985-1986  |
|                               |           | 2011-2012  | 1985-1986  | 1985-1986  | 1985-1986  |
Extremely dry 1992-1993

Extremely wet periods in Poprad and Svit were recorded in SDI 2004-2005 and in SPI, RDI and SPEI 2009-2010. Severely wet periods were recorded in SDI and SPI in 1963-1964, 1974-1975. In SDI in 1969-1970 and 1974-1975, in SPI 2006-2007 and 2013-2014. In RDI and SPEI, the same extremely wet periods in 1964-1965, 1969-1970, 1971-1972, 1974-1975, 2013-2014, occurred (Table 5).

It Streda nad Bodrogom and Košice there were three extremely wet periods in SDI 2009-2010 and in SPI, RDI and SPEI 2009-2010. Severely wet periods were recorded in SDI and SPI in 1963-1964, 1974-1975. In SDI in 1969-1970 and 1974-1975, in SPI 2006-2007 and 2013-2014. In RDI and SPEI, the same extremely wet periods in 1964-1965, 1969-1970, 1971-1972, 1974-1975, 2013-2014, occurred (Table 5).

In Humenné and Kamenica nad Cirochou, three extremely wet seasons were recorded in SDI 1966-1967, 1972-1973, 2002-2003 and in RDI 1990-1991. There was one severely wet period in SDI in 1997-1998 and in RDI 2009-2010, see Table 5.

Four extremely wet seasons were found in Krásno Brod and Tisinec Table 5. Severely wet periods were recorded four see (Table 5).

Chmeľnica and Červený Kláštor were found to have one extremely wet period in the SDI index 2003-2004. Three severely wet periods were recorded in the SDI index 1963-1964, 1973-1974 and in SPI 1964-1965 (Table 5).

In Stratená, Švedlár and Mníšek nad Hnilcom four extreme wet periods were recorded in SDI 1964-1965, 1974-1975, SPI 1989-1990 and RDI and SPEI 2009-2010. Severely wet periods occurred in SDI 1971-1972, 1976-1977, 2009-2010, 2012-2013 and in SPI 1984-1985 (Table 5).

Table 5. Assessment of 12 monthly index for all station for wet season.

| Wet season | Station/index | Season | SDI | SPI | RDI | SPEI |
|------------|---------------|--------|-----|-----|-----|-----|
|            | Svit/Poprad   | Severely wet | 1964-1965 | 1964-1965 | 1964-1965 | 1964-1965 |
|            |               |         | 1969-1970 | 1974-1975 | 1969-1970 | 1969-1970 |
|            |               |         | 1971-1972 | 2006-2007 | 1971-1972 | 1971-1972 |
|            |               |         | 1974-1975 | 2013-2014 | 1974-1975 | 1974-1975 |
|            |               | Extremely wet | 2004-2005 | 2009-2010 | 2009-2010 | 2009-2010 |
|            | Streda nad Bodrogom/Košice | Severely wet | 1973-1974 | 1960-1961 | 1990-1991 | 1986-1987 |
|            |               | Extremely wet | 2009-2010 |           |           |       |
|            | Humenné/Kamenica nad Cirochou | Severely wet | 1997-1998 | 1966-1967 | 1990-1991 | 2009-2010 |
|            |               | Extremely wet | 1972-1973 | 2002-2003 |           |       |
|            | Krásny Brod/Tisinec | Severely wet | 1964-1965 | 2000-2001 | 2009-2010 | 1983-1984 |
|            |               | Extremely wet | 2004-2005 |           | 1990-1991 |       |
|            | Chmeľnica/Červený Kláštor | Severely wet | 1963-1964 | 1964-1965 | 1964-1965 | 1964-1965 |
|            |               | Extremely wet | 1973-1974 |           |           |       |
|            |               |           | 2003-2004 |           |           |       |
Periods that are common for more stations and/or more indices are marked in red.

5. Conclusion
The work was focused on evaluation of dry and wet periods by SDI, SPI, RDI and SPEI drought indices in time series 1960-2015 in time step 12 months. The results of the evaluation of six sites show several dry and wet periods common to all locations common dry periods represented 1963-1964, 1965-1966, 1981-1982, 1985-1986, 2011-2012. Common wet periods represented 1964-1965, 1969-1970, 1971-1972, 1974-1975, 2006-2007, 2009-2010, 2013-2014. The results have shown that dry and wet periods alternate. The indices evaluated differed in the input indicators, but nevertheless the same common assessment periods were based. Especially in the evaluated stations Poprad/Svit. The results show that dry periods also occurred in the north of eastern Slovakia.
The evaluated time step of 12 months reflects changes in water accumulation in water reservoirs; on the basis of these results we can determine adaptation measures in the evaluated area eg. in wet periods, retain water in the landscape by suitable water management constructions such as: retention tanks, small water reservoirs, polders, docks and other measures. During the drought, it is necessary to overestimate the water levels in the catchments, to irrigate the area and various other measures.

Acknowledgment
This work is thankful to be supported by project of the Ministry of Education of the Slovak Republic VEGA 1/0217/19 Research of Hybrid Blue and Green Infrastructure as Active Elements of a ‘Sponge City and the project od Slovak Research and Development Agency APVV-18-0360 Active hybrid infrastructure towards to sponge city.
This work has been also supported by SRDA SK-PT-18-0008 project: Hydrological risk: from excess to scarcity of water.

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