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Evaluation of drought using standardised precipitation and flow indices and their correlations on an example of Sinjsko polje

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Professional paper

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Evaluation of drought using standardised precipitation and flow indices and their correlations on an example of Sinjsko polje

Sinjsko polje is a karst polje situated in the central part of the Cetina River. It occupies an area of 62 square kilometres and has mostly been ameliorated, thus presenting favourable conditions for agriculture. The standardised precipitation index (SPI) and the standardised streamflow index (SSI) are used in this paper for drought analysis. Weather data for the Sinj Station, and hydrological data for the Han and Grab stations, collected in the period from 1981 to 2010, are considered. The SPI and SFI values are used to define drought periods characterized by their duration, intensity, and magnitude.

Key words:
karst field, drought, precipitation, streamflow, Cetina

Stručni rad

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Ocjena suše primjenom standardiziranog indeksa oborine i protoka te njihov odnos na primjeru Sinjskog polja

Sinjsko polje je krško polje i nalazi se u središnjem dijelu rijeke Cetine. Obuhvaća 62 km^2, a većim je dijelom meliorirano s povoljnim uvjetima za poljoprivredu. Za analizu suše u ovome radu primijenjeni su standarizirani indeks oborine (SPI) i standardizirani indeks protoka (SSI). Razmatrani su meterološki podaci sa stanice Sinj i hidrološki podaci sa stanica Han i Grab iz razdoblja 1981-2010. Pomoću vrijednosti SPI i SSI određena su sušna razdoblja koja su izražena pripadnim trajanjem, intenzitetom i magnitudom.

Ključne riječi:
krško polje, suša, oborina, protok, Cetina

Fachbericht

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Standardisierter Niederschlags- und Durchflussindex zur Dürrebewertung und ihr Verhältnis am Beispiel des Feldes Sinjsko Polje

Das Karstfeld Sinjsko Polje befindet sich im mittleren Teil des Flusses Cetina. Es umfasst 62 km2 und ist größtenteils melioriert mit günstigen Eigenschaften für die Landwirtschaft. Zur Dürreanalyse wurden in dieser Arbeit der standardisierte Niederschlagsindex (SPI) und Durchflussindex (SSI) angewandt. Meteorologische Daten der Station Sinj und hydrologische Daten der Stationen Han und Grab aus dem Zeitraum von 1981 - 2010 wurden betrachtet. Aufgrund der SPI und SSI Werte wurden Trockenzeiten ermittelt sowie mit Dauer, Intensität und Magnitude beschrieben.

Schlüsselwörter:
Karstfeld, Dürre, Niederschlag, Durchfluss, Cetina

1. Introduction

Sinjsko polje is one of the largest karst fields in the Croatian region of Dalmatia. Agriculture has a long-standing tradition in this area. Therefore, extensive land-improvement works have been initiated in the second half of the 20th century to ensure favourable conditions for intensive agriculture. To the present date, the planned works have not been fully realized, and the crops are therefore exposed to periodic flooding in the rainy season, as well as to drought during summer.

A network of canals is used for the drainage and irrigation of the Sinjsko polje. The existing canals are approximately 150 km in total length. Although about 20 square kilometers could be irrigated based on the present amelioration system, only a quarter of this area, or about 5 sq. km, is systematically irrigated. A part of the agricultural land located in peripheral zones is out of reach of water from irrigation canals, thus making the irrigation impossible. Also, cultivated land that is located outside the amelioration area can not be irrigated. Consequently, a significant part of the Sinjsko polje is irrigated exclusively in natural way i.e. by precipitation and by capillary action from the soil. The corresponding yields primarily depend on precipitation regime. Due to climatic conditions, yields in areas without irrigation vary from year to year. The effects are particularly pronounced in dry years with minimum yields and huge economic losses. Therefore, drought has been declared a natural disaster in the Sinjsko polje on several occasions in the past 20 years (e.g. in 2000, 2003, and 2012). In Split-Dalmatia County, in which the Sinjsko polje is located, drought is a significant natural hazard accounting for 19 % of economic losses, and is in this respect second only to the storm-generated losses (26 %). The third-ranking natural hazard is fire, i.e. forest fires that are usually triggered by long dry periods in the warm half of the year.

Droughts can be classified into four main categories: meteorological, hydrological, agricultural, and socio-economic droughts [1]. They are related to the deficit precipitation, streamflow, soil moisture, or the combination of the three. An analysis of precipitation and streamflow data series is performed in the present study in order to identify and quantify the meteorological and hydrological drought deficit in the Sinjsko polje. No soil moisture measurements have been made in the area although such information would be necessary to ensure relevant identification of agricultural drought. However, meteorological drought data [2, 3], enable (only) a quantitative estimation of agricultural droughts. Moreover, some authors use the Standardized Precipitation Index (SPI) as an agricultural drought indicator, since it is strongly related to crop production [4].

In the present paper, the drought analysis is performed using the SPI, which is extensively applied in meteorological drought monitoring practices [5-15]. A similar SPI calculation concept is also applied on the streamflow data using the Standardized Streamflow index (SSI). The two indices are then compared on different time scales following the procedure described in the paper presented by Vicente-Serrano and Lopez-Moreno [16]. They compare two hydrological indices – inflow rate and water level at the Yesa reservoir in the most upstream part of the river Aragon catchment (2181 km^2) in the Pyrenees (Spain). The authors point out that drought should be analysed at different time scales. Their study confirms that the SPI time scales are useful for monitoring droughts in various usable water resources. They emphasize the need for testing usefulness of drought indicators to monitor different drought types prior to development of monitoring plans. Finally, they conclude that future research is needed in other basins to determine the relationships between the time of response of hydrological variables to climatic characteristics and the water resources management.

Medved-Cvikl et al. [17] analyse the relation between monthly runoffs and climate conditions at three catchments in Slovenia, ranging from 859 km^2 to 2,284 km^2 in area, using the SPI (Standardized Precipitation Index) and SSI (Standardised Streamflow Index). The authors note that the correlation of these variables could be significant, and so this approach can be a useful meteorological and hydrological drought management tool.

Similarly, Rimkus et al. [18] analyse hydrological and meteorological drought phenomena using the Standardized Precipitation Index on the Neman River (97,864 km^2), which mostly influences the area of Lithuania, and the area of four neighbouring countries. They use data from 21 meteorological and 15 hydrological stations, covering the period from 1961 to 2010. In that period, no changes in the frequency of drought and its intensity were established. The area occupied by the Neman River basin exceeds that of the Sinjsko polje by about 1,600 times. Therefore, one precipitation station and two hydrological stations analysed for the Sinjsko polje constitute a satisfactory station density because they are placed within an area of about 61 sq. km.

Haslinger et al. [19] present a regional analysis of the link between meteorological drought indices and streamflow for different catchments in Austria, with areas ranging from 13 to 622 sq. km. They have established that a significant correlation exists between the meteorological data and streamflow, except for catchments where groundwater storage and snow processes are important.

The main objectives of this study are the identification and quantification of meteorological and hydrological drought data, and the determination of their relationship in the karst field area of the Sinjsko polje.

2. Study area

The Cetina River, 105 km in length, runs in its entire course through the region of Dalmatia, itself situated in the southern part of Croatian littoral. The Cetina River group of springs is located on the slopes of Dinara Mountain at an altitude of 382 m above sea level. The River flows in the south-east direction toward Peruča Lake (reservoir). To the downstream of Peruča Dam, the River passes through the Hrvatsko polje, and then through the Sinjsko polje, which is the largest karst field (polje) in the Cetina River catchment area. In the most downstream reaches, the river runs through canyons, changes direction of flow to the west, and finally flows into the Adriatic Sea (at the town of Omiš). Five hydroelectric power plants (HEPP) (Peruča, Orlovac, Đale, Kraljevac and Zakučac) are located along the Cetina River and its tributaries. Therefore, the water regime of the river is directly influenced by the operation of hydropower plants (Figure 1.a).

The Sinjsko polje, with its area of about 62 sq. km, is one of the largest karst fields in Dalmatia. It is about 12 km long and about 5-6 km wide, and is surrounded by the mountains of Dinara, Kamešnica and Svilaja, as well as by some lower hills in Trilj area.

The altitude of the Sinjsko polje varies between 293 and 300 m a.s.l. Land reclamation started in the middle of the twentieth century and compriesed about 42 sq. km or about 65 % of the total field area. But proper conditions for a stable, high-yielding, and crop-intensive agricultural production have not as yet been achieved. The reasons for this are primarily of organizational and technical nature, although the importance of natural factors such as climate and hydrology should not be disregarded. Therefore, the existing water management and agronomic system is characterized by occasional excess (surplus) or deficit of water.

The precipitation data from the Sinj weather station, and streamflow data from the Han and Grab hydrological stations at the Cetina River and its tributary, comprising the available 30-year measurement period (1981-2010), were used for the purposes of this study. The Cetina River is the main source of water for agricultural irrigation in the Sinjsko polje. The irrigation water is taken from the river at about 1.5 km downstream of Han, and diverted into the canal network. Thus, the surface water input into this system is registered at Han. It is a flow of water that comes from the entire upstream part of the catchment (F = 1,650 sq. km). In this zone, the Cetina River flow is under the direct influence of the HEPP Peruča in operation since 1960, which is located about 13 km upstream of Han, and has a topographic catchment of 1,200 km^2. The Sinj weather station, which started operating in 1949, is situated at the northwestern border of the field. The station's coordinates are 43 ° 43 'N and 16 ° 40' E, and it is situated at an altitude of 298 m (Figure 1.b). It is the only weather station in the field that operates as a part of the main station network of the Meteorological and Hydrological Service of Croatia (DHMZ). Two additional DHMZ raingauge stations, Han and Trilj, are also in operation in the wider area of the field. An average annual temperature in the field is 12.9°C. The annual precipitation varies between 822 mm and 1,686 mm, with the average of 1,146 mm in the 1981-2010 period. The lowest average precipitation values are registered in July (42 mm) and the highest in November (163 mm). Two specific half-year periods are important from the agricultural standpoint: warm period (or vegetation period – from April to September) and cold period (from October to March). On average, only 457 mm of precipitation, or about 40 % of the total annual precipitation, can be expected In the vegetation period, while the average value of 689 mm of precipitation can be expected in the cold period.

Some general data for the two hydrological stations are given in Table 1. The Han station is located on the downstream side of the bridge across the river (Figure 1.b), about 4.1 km to the northeast of the Sinj weather station. The measurements at the

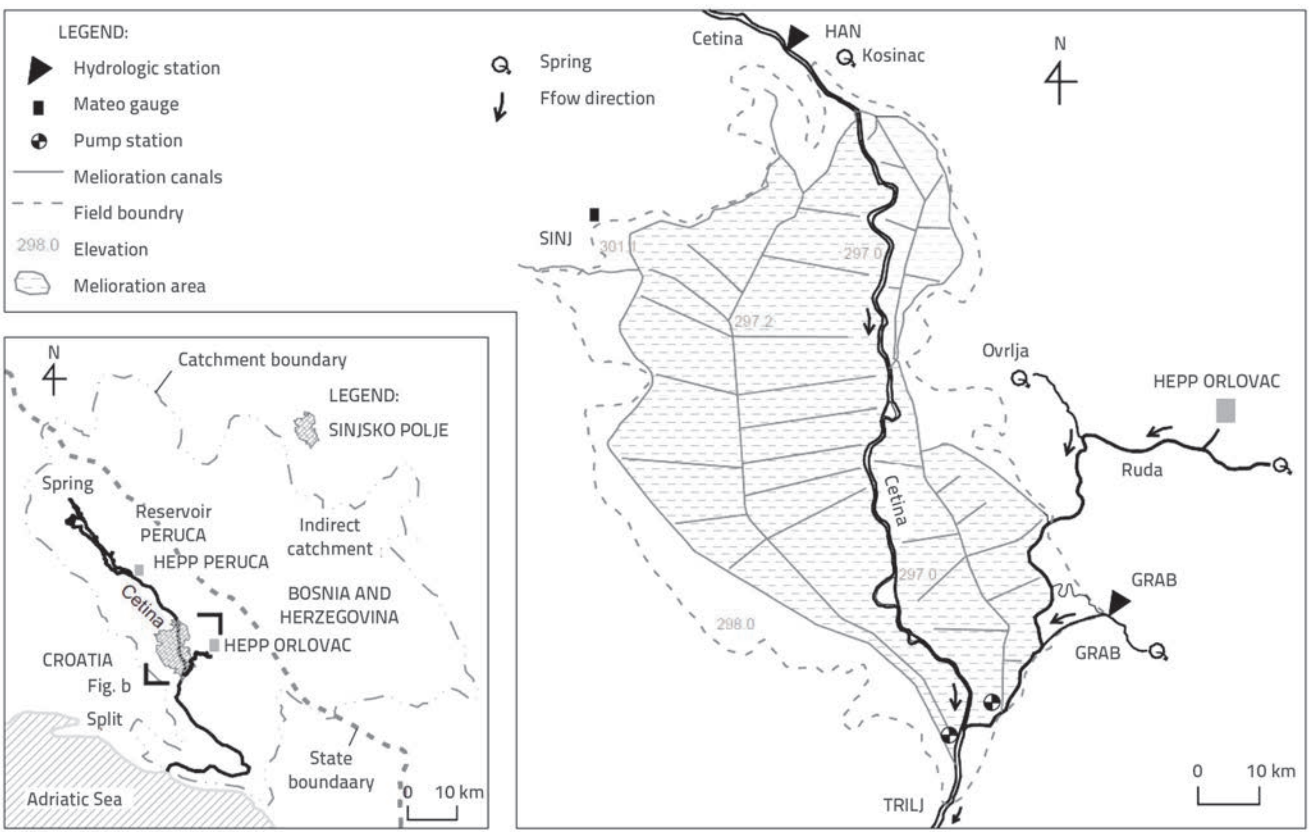

Figure 1. a) Cetina River catchment area: b) layout plan of Sinjsko polje

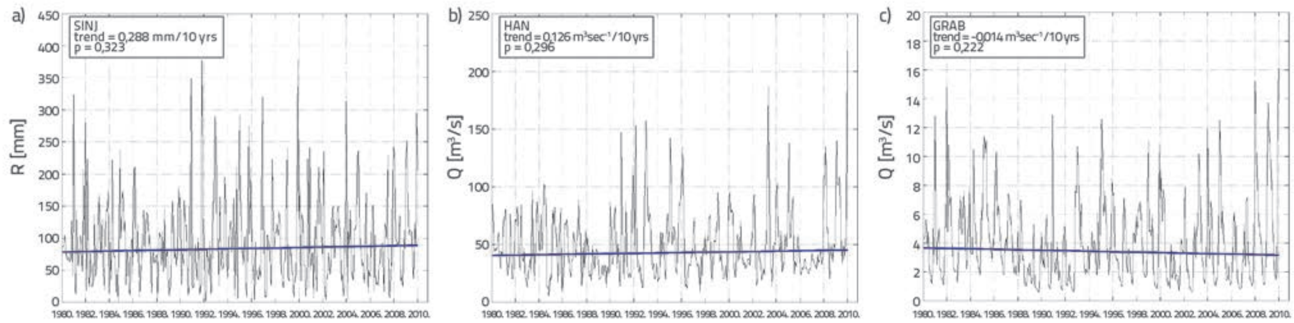

Figure 2. Time series of monthly, for the 1981-2010 period: a) precipitation (R) for Sinj: b) streamflow (Q) for Han; c) Grab (A line indicates the Sen slope whose value is indicated in the upper left corner along with statistics p for assessing significance of the trend)

station started in the late 19th century. The water level recorder was installed in 1957. In summer months, an average minimum flow varies between 30 and 40 $m^3\ s^{-1}$ while the flow is the highest in winter months, with a monthly average of about 60 $m^3\ s^{-1}$. Flows in excess of 100 $m^3\ s^{-1}$ can occur in all months of year, and the same applies to low flow rates of only a few $m^3\ s^{-1}$. The highest recorded flow in the observed 30-year period was 331 $m^3\ s^{-1}$ (14 Apr 2004, H = 300.19 m a.s.l.), and the lowest one was 1.6 $m^3\ s^{-1}$ (12 Oct 1983, H = 296.52 m a.s.l.) (Figure 2).

Table 1. General hydrological data for stations Han and Grab

Gauging station	Han	Grab
Watercourse	Cetina	Grab
Established	1894	1964
Actual level (m a.s.l.)	296.63	295.45
Average annual streamflow [m^3/s]	50.0	4.1
Minimum streamflow [m^3/s]	1.6	0.41
Maximum streamflow [m^3/s]	331	37.5

About 1 km upstream of Trilj, the Cetina River receives water from the Ruda and Grab rivers. The flow of the Ruda River is under the direct influence of the HEPP Orlovac (built in 1972). The Grab watercourse has a natural hydrological regime, and the flow depends on the generosity of its source and on water collected from its own basin. Therefore, the Grab hydrological station is taken into account in this paper, in addition to the Han station which is strongly under the human impact due to the HEPP operation. The Grab station is located on the Grab River at about 800 m downstream of its spring, and it started operating in 1964. It is situated about 10 km to the south-east of the Sinj weather station. Mean annual inflow of the Grab River to the Ruda River is 4.1 $m^3\ s^{-1}$, with the lowest recorded flow of 0.41 $m^3\ s^{-1}$ (21 Sep 1992), and the highest recorded flow of 37.5 $m^3\ s^{-1}$ (24 Dec 1982) (Table 1 and Figure 2).

3. Methods

In order to calculate the SPI values on different time scales (*n* months), it is first of all necessary to obtain the cumulative sum of precipitation amounts for each month and *n* months backwards. Then a two-parameter gamma distribution is fitted to the obtained series of the associated time scale, and the maximum likelihood method is used to determine α and β parameters [20]. A long time period of at least 30-years is needed for the estimation of parameters. The 1981-2010 reference period based on available hydrological and meteorological measurements is used in the present study. The obtained theoretical cumulative distribution function is further transformed into the standardised normal distribution. SPI values determine deviation from the median expressed in the units of standard deviation. Negative SPI values point to the potential precipitation deficit at the station. The drought intensity classification according to [21] is given in Table 2.

The principal advantage of the SPI is that it enables estimation of the beginning and end of drought as well as its intensity. A dry spell for a certain time scale can be determined from the SPI value sequence by finding the first value lower than -1. The consecutive series of negative SPI values (SPI < 0) determines duration of dry spell, which ends when the SPI reaches the positive or zero value. The magnitude (M) of such dry spell is the sum of associated SPI values in dry spell of duration *D*:

$$M = \sum_{i=1}^{D} SPI(i) \tag{1}$$

Dry spells are determined for different time scales (1, 3, 6, 9, 12 and 24 months) and the associated magnitudes are calculated. An advantage of the SPI lies in the possibility of calculating the SPI value for various time scales, thus making this index valuable not only for meteorological drought monitoring but also for agricultural and hydrological droughts.

The same approach was used for streamflow values at the Han and Grab hydrological stations, resulting in the Standardized Streamflow Index (SSI). This enabled comparison of meteorological and hydrological variables. Namely, McKee et al. (1993) [21] indicated that since SPI requires only one input variable, it could be applied in a similar way to snowpack, streamflow, reservoir storage, soil moisture, and ground water. However, we made a preliminary statistical analysis and tested the goodness of fit of gamma distribution to empirical data (not shown). Graphical checks as well as the chi-square test both confirmed the gamma distribution to be an acceptable theoretical distribution for fitting Han and Grab discharge series. The correlation between the SPI and SSI values on different time scales was made in two ways, partly according to [16]: the continuous comparison (considering all months in a continuum), and monthly comparison. The Pearson correlation coefficient was used for this comparison.

In order to detect time changes in precipitation and streamflow during the 30 years period (1981-2010) the trend was estimated by means of the Kendall' tau method (or Sen's slope). This estimator of slope is statistically robust and resistant as opposed to the least squares estimator. The statistical significance was tested by the Mann-Kendall test using the confidence level of 5 % [22].

Table 2. The classification scale for SPI values

SPI	Category
≥ 2	Very humid
1.5 do 1.99	Humid
1.0 do 1.49	Moderately humid
-0.99 do 0.99	Normal
-1.0 do –1.49	Moderately dry
-1.5 do –1.99	Dry
≤ -2	Very dry

4. Results

The trend results reveal a weak, statistically insignificant increase in annual precipitation values (0.29 mm/10yrs) and streamflow values at Han station (0.13 $m^3 s^{-1}$ per decade), and a weak decrease at Grab station (-0.014 $m^3 s^{-1}$ per decade) during the analysed 30-year period (Figure 2).

The SPI series are given in Figure 3. a while the SSI series on the time scales from 1 to 24 months are presented in Figures 3.b and 3.c. Minimum calculated values of SPI and SSI for various time scales are presented in Table 3, with the corresponding amounts of precipitation (R) and the associated streamflows (Q). Results show that drought periods differ, both in intensity and duration, over the analysed 30-year period. The extreme values of the SPI index occurred in 1985, 1990, 1997, 2003, and 2008 for the selected time scales. The longest dry periods were mainly observed in the last decade of the analysed period for the time scales of up to 12 months. However, for the time scale of 24 months, the longest dry period began in February 1989 and lasted 34 months (Table 3). So, the drought frequency is higher and the droughts are less intense for shorter time scales, compared to longer scales. On the other hand, at longer time scales (9, 12 and 24 months), drought is less frequent, but it is characterised by longer duration and greater magnitude. Contrary to precipitation conditions, streamflow data (SSI - Han) show the strongest drought in the 1980s, including the year of 1990, when the drought index had a minimum value for more time scales (Table 3). This may be a consequence of the HEPP regime, i.e. a smaller discharge from the Peruča reservoir compared to the permitted biological minimum (3.5 $m^3 s^{-1}$) in previous years.

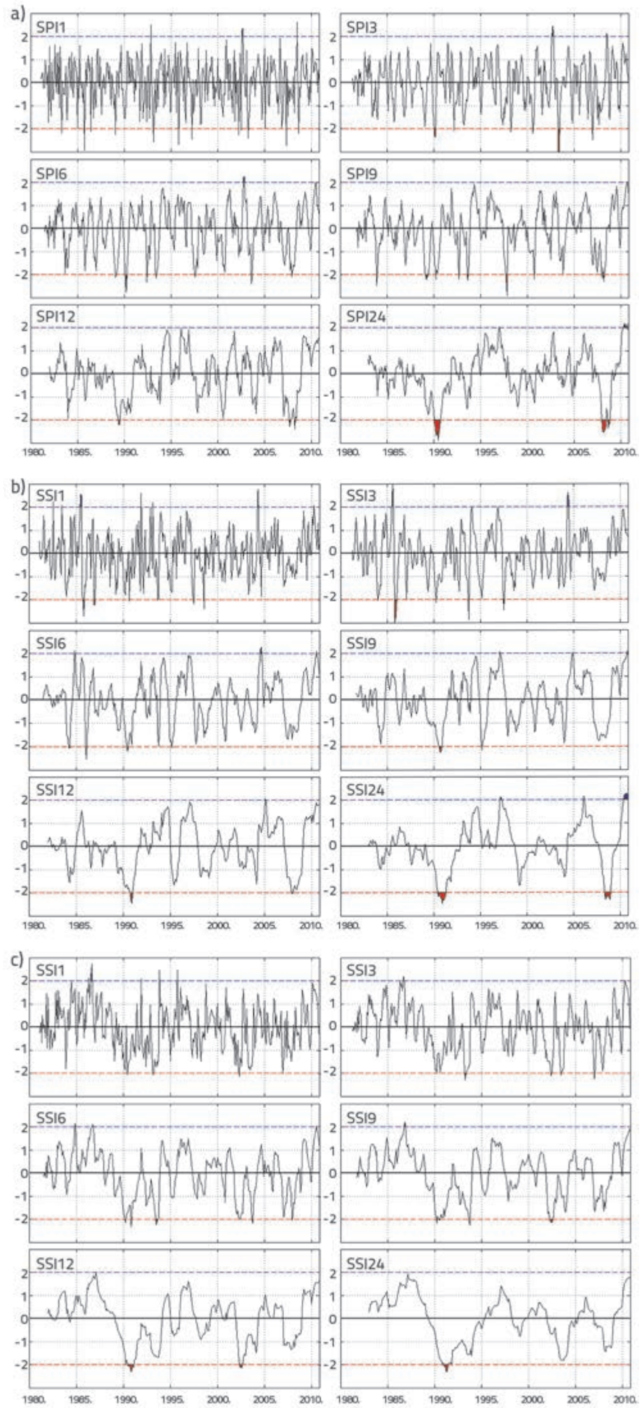

Figure 3. Time series of for the 1981-2010 period: a) SPI; b) SSI-Han; c) SSI-Grab (The red (blue) dashed line indicates extremely low (high) cumulative amount of rainfall for the corresponding time scale 1, 3, 6, 9, 12, and 24 months)

Table 3. Minimum SPI, SSI-Han and SSI-Grab values for different time scales and associated precipitation

Time scale	1	3	6	9	12	24
			SPI			
Year	1985	2003	1990	1997	2008	1990
Month	September	May	Februar	October	March	Juni
SPI	-2.9	-3.1	-2.8	-2.9	-2.4	-2.9
R [mm]	0.7	84.4	272.5	427	737	1739.7
Dmax	4	11	12	20	24	34
Year	2000	2007	1999	2006	2006	1989
Month	Juni	Juni	November	November	December	February
M	3.7	10.2	11.6	27.5	34.1	47.5
			SSI-Han			
Year	1985	1985	1986	1990	1990	1990
Month	October	December	January	September	November	November
SSI	-2.7	-3.0	-2.5	-2.3	-2.5	-2.5
Q [m³/s]	5.6	31.5	104.4	226.0	313.5	769.0
Dmax	7	19	21	24	27	32
Year	1983	2007	1997. 2007	1989	1989	1990
Month	October	January	August, March	Juni	May	January
M	8.6	18.5	17.9	31.1	37.0	47.1
			SSI-Grab			
Year	2002	1993	1990	1993	1990	1991
Month	April	March	October	September	October	March
SSI	-2.1	-2.3	-2.3	-2.3	-2.3	-2.3
Q [m³/s]	1.8	3.7	5.7	11.0	20.1	51.7
Dmax	10	29	32	28	50	62
Year	2001	1989	1992	2001	2002	2002
Month	October	January	May	December	March	December
M	14.0	29.7	37.0	33.6	42.0	41.5

D_{max} denotes maximum duration of dry period (in months) and its beginning with the corresponding magnitude, associated to different time scales (1, 3, 6, 9, 12, and 24 months)

Today hydrological conditions in the Cetina river bed are more favourable due to the regulated and controlled relations between the electricity and water management authorities. The last streamflow below the biological minimum was recorded at Han in 2003. The values of SSI-Grab were the smallest in 1990, 1991, and 2002. The longest drought periods were recorded in 1989, 1992, 2002, and 2003. Similar to meteorological drought, the hydrological drought is of longer duration and greater magnitude for large time scales (24 months) although they occur rarely. For shorter time scales, hydrological drought has a shorter duration and lower intensity, but occurs more frequently.

From an agronomic point of view, SPI6 and SSI6 for September are very important because they include the growing (vegetation) season. Table 4 provides the lowest 20 % of the SPI6 and SSI6 values calculated for September. According to the SPI values, there was no recorded extreme dry meteorological drought in the Sinjsko polje, but very dry periods were registered (in 1985, 1990, 1992, 1997, 2000, 2003, and 2007). However, streamflow values at Grab point to an extremely dry vegetation period in 2003 when SSI6 for September was less than 2. Very dry six months periods occurred in Grab and Han mostly in the 1990s as well as in the early 2000s.

Figure 4.a shows the Pearson coefficient of correlation between the SPI and SSI – Han for continuous series (left panel) and for each month (right panel). The correlation coefficient in continuous series has positive values with a continuous increase corresponding to an increase in timescale. For the shortest monthly scale (SPI1 vs. SSI1), the correlation is the weakest and the coefficient is 0.22, while for the time scale of 24 months the coefficient of correlation of the corresponding indices has the maximum value of 0.7 (SPI24 vs. SSI24). Thus, the relationship between the streamflow and precipitation is more apparent for larger time scales. Since the Cetina streamflow slowly responds to short SPI time scales, the SPI may not be useful for

Table 4. Minimum values of SPI6, SSI6-Han and SSI6-Grab for September (vegetation period) and corresponding year

No.	Year	SPI6	No.	Year	SSI6-Han	No.	Year	SSI6-Grab
1.	2000	-1.91	1.	1993	-1.95	1.	2003	-2.18
2.	2007	-1.82	2.	1997	-1.89	2.	1993	-1.94
3.	1985	-1.42	3.	1998	-1.43	3.	1990	-1.41
4.	1992	-1.34	4.	1990	-1.36	4.	1992	-1.11
5.	1997	-1.3	5.	2000	-1.17	5.	1997	-0.98
6.	2003	-1.05	6.	2003	-1.11	6.	2002	-0.88

hydrological drought analysis for this watercourse. That could be explained by the fact that the streamflow at Han can be divided into two components: natural and artificial. The natural part of the streamflow is formed by rainfall from the catchment area between Han and Peruča. The artificial component is the streamflow released from the HEPP Peruča, which is controlled by human activity. Based on the correlation analysis, it can be concluded that the natural runoff component has a significant role only at larger time scales when the correlation between the precipitation and streamflow is significant. On the other hand, the shorter time scale streamflow at Han mainly depends on human activity (HEPP), and almost no or a very slight connection exists with rainfall regime.

According to the relationship established between the SSI-Han and SPI per month for each time scale, it is also possible to define a visible correlation proportional to the time scale (Figure 4.a, right panel). The minimum correlation value was registered for the shortest time scale of one month, while in November and December this value is statistically significant (according to *t*-test with the 95 % confidence level). For the three-month scale, the relationship between

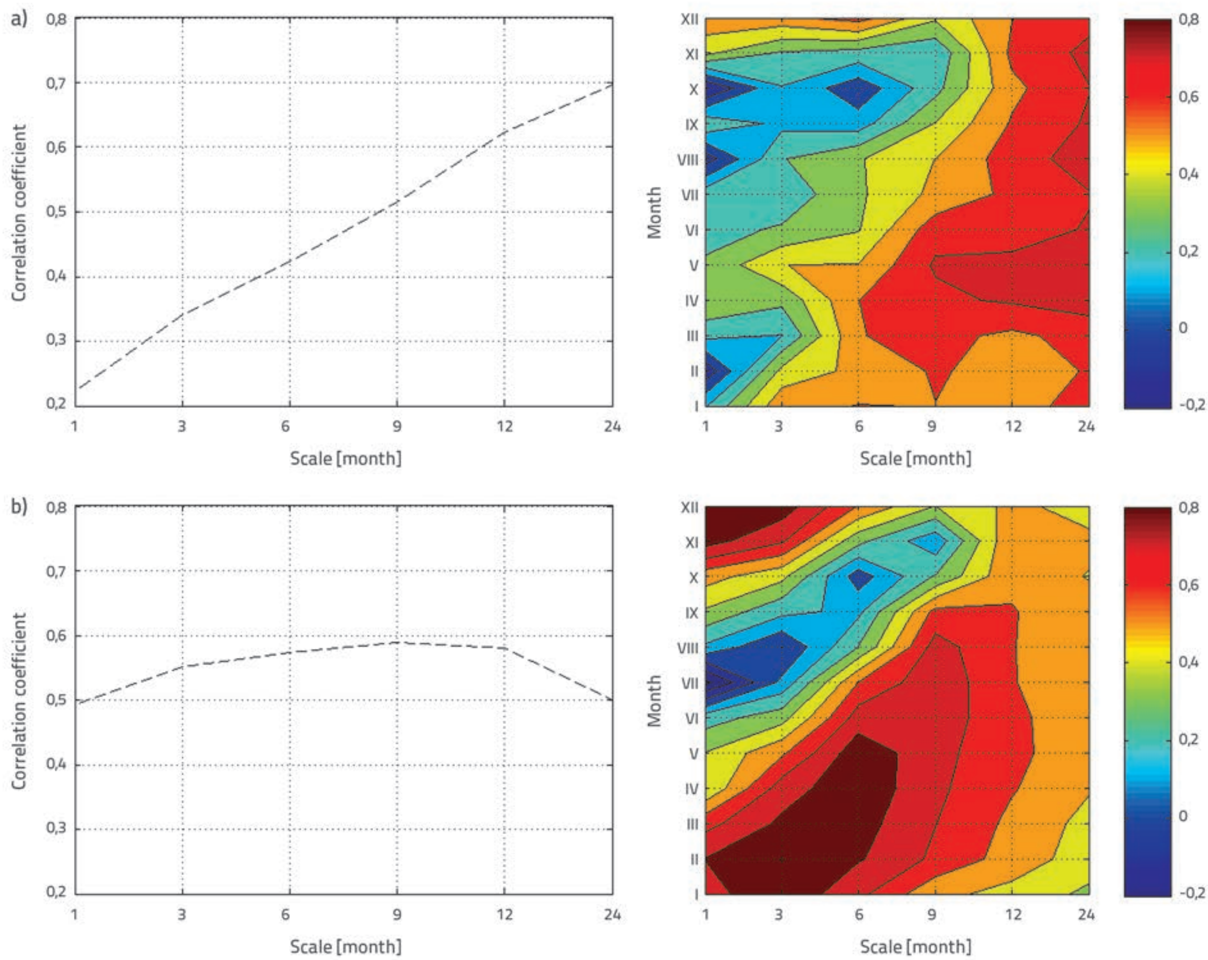

Figure 4. Correlation coefficients between SPI and a) SSI-Han and b) SSI-Grab for a continuous series (left) and for each month (right), for different time scales (in months)

the precipitation and discharge is more pronounced in January, February, May, and December compared to other months. For the six-month scale, the relationship is significant in all seasons except in autumn (September to November), while for the 9-month the r-value is not significant in October and November only. For higher time scales (12 months), the correlation between the streamflow and precipitation is statistically significant in all months with the corresponding r values higher than 0.5. In this case, there was no evident seasonal nature of connectivity between the precipitation and streamflow indices, but it was dependent solely on the length of time scales.

A similar presentation of correlation between the SPI and SSI-Grab is provided in Figure 4.b. The correlation coefficients for continuous series have very similar r-values for all time scales, ranging between 0.5 and 0.6. On a monthly scale, the strongest correlation ($r > 0.7$) of precipitation (SPI) and streamflow (SSI-Grab) is generally obtained in the coldest months (November to February) for one- and three- month time scales, but also in spring months (April and May) for the six-month scale. The blue 'tongue' formed in Figure 4.b right represents non-significant correlation values.

5. Discussion

Vicente-Serrano and Lopez-Moreno [16] show that continuous series on the Aragon River (1950-2000) exhibit a significant correlation between the SPI and streamflow for the time scales of up to 3 months ($r > 0.5$), after which the level of correlation decreases. The maximum occurs at the scale of 2 months with the correlation coefficient of $r = 0.63$. In their study, the correlation between the water level and the SPI is significant for the scales of 7 to 10 months ($r > 0.5$), while the correlation decreases for other time scales. They argue that the SPI is not suitable for determining the hydrological drought at longer time scales (> 12 months). It should be noted that hydrological parameter - water level in the reservoir - also has a partly artificial character. Its value depends on the inflow from the upstream catchment, but also on the release of water from reservoir, i.e. abstraction for water supply and agriculture. The results of correlation analysis at the Sinjsko polje and station Han are in contradiction with the Aragon River results because they show a continuous increase of correlation coefficient. The reason for such an atypical result could probably lie in the fact that the streamflow in this location is under a direct and strong influence of the upstream HEPP. On the other hand, a maximum correlation coefficient for Grab stations was established for the nine month time scale ($r = 0.56$), with lower values for shorter or longer scales. Such a shape of the curve corresponds to results obtained at the Aragon River where the SPI - water level relation - has a maximum for eight months while SPI - flow relation - has a maximum for the 2 month scale.

Furthermore, monthly series at the Aragon River [16] exhibit a highly seasonal character. Thus, the most significant correlation ($r > 0.7$) SPI - flow - was determined in the cold season (autumn and winter) for shorter time scales (up to 6 months). Water level has the most significant correlation in the late autumn and winter for scales ranging from 4 to 10 months. In the Sinjsko polje, the Cetina River (station Han) does not have a seasonal connectivity between the hydrologic index and precipitation, but their relationship is weaker for shorter and stronger for longer time scales. The Grab watercourse has the strongest correlation ($r > 0.7$) in the winter and spring months for a shorter time scale (from 1 to 6 months).

Rimkus et al. [18] note that the standardized precipitation index cannot successfully identify the hydrological summer droughts in an area where the spring snowmelt accounts for a large part of the annual flow. Also, Medved-Cvikl et al. [17] stress that the effects of soil and rock retention, as well as the relief characteristics of the region, influence the correlation between the precipitation and streamflow indices at all stations. Therefore, runoff coefficients for watercourses differ considerably among individual regions of Slovenia.

It is evident that almost every unit, e.g. hydrological basin, karst field, etc. has its own specificities arising from its physical structure (geology, topography, soil, vegetation), climate conditions (rainfall regime, snow cover, evaporation rate) and dam operation and, therefore, each such unit can almost be regarded as a unique system that has to be studied and analysed separately. In any case, experience from other sites has proven to be quite useful in drought analysis. The correlation analysis presented in this work highlights the difference between the catchment with a controlled management of water regime (Cetina), and the catchment with natural regime (Grab). Water regime is also influenced by other parameters such as catchment size, geology etc. It must be stressed that this site is located in the Dinaric karst, which is characterised by highly complex hydrological and hydrogeological relations. Therefore, hydrological processes as well as meteorological and hydrological relations require extensive research. Furthermore, this paper also points to the need of systematic analysis of the SSI estimation based on various theoretical distributions, which is planned in the scope of future work.

6. Conclusion

The application of the SPI index for the determination of meteorological drought is presented in this paper. The same concept was applied to hydrological data (streamflow), and so the SSI index was determined. The analysis was conducted for the time series of monthly precipitations (Sinj) and streamflow data (Han and Grab) covering the 1981-2010 period.

Extreme meteorological droughts occur at every 5-6 year intervals in a given area. The least favourable hydrological conditions were recorded at the Cetina River (Han) in the 1980s, including the year of 1990. Since the Cetina streamflow is directly influenced by the operation of the HEPP Peruča, the authors consider that the minimum drought indices correspond to the period when water regulations were not sufficiently respected. However, minimum prescribed streamflows at the HEPP are more respected in the present situation, which is useful for hydrological drought mitigation. On the other hand, minimum drought indices were recorded at the Grab natural watercourse in 1990, 1991, and 2002.

Regarding the meteorological and hydrological deficit, which may have a great impact on agricultural conditions, it can be said that they are particularly unfavourable at every 3-4 year intervals. There is a significant correlation between the meteorological and hydrological deficit at larger time scales in the Cetina River (Han) (12-48 months), which is not useful for drought identification. On the other hand, the winter-spring correlation between meteorological and hydrological indices was recorded at shorter time scales (up to 6 months) at the Grab. Besides, the summer streamflow index for the Grab has the strongest correlation with precipitation for the 9-month scale. This shows that the summer flow strongly depends on precipitation in the winter-spring period. Therefore, the SSI (Grab) could be useful for identification of drought in this area, especially with regard to natural regime.

Several authors emphasized in their works the importance of studying drought at different temporal and spatial scales [16, 17, 19]. Also, some of them [17, 19] pointed out that natural factors such as the geological structure, precipitation processes etc. exert a significant influence on the interaction of meteorological and hydrological parameters. The anthropogenic factor, manifested through hydro-power use of water and water supply, is also added as it can have a very strong influence on the meteorological - hydrological relationships. This shows that water management could be successfully applied for drought mitigation in the controlled catchments such as the Cetina. It could be very useful to release adequate quantities of water from the HEPP, especially in the vegetation period, without precipitations, when natural watercourses are weak or dry.

Finally, it should be stressed that this analysis is the first step in the study of drought in the Sinjsko polje and that plenty of possibilities remain for the continued study of meteorological and hydrological issues. In particular, a systematic and detailed investigation on fitting the theoretical distribution for SSI calculation would be appropriate since there is a lack of studies and practical usage of the SSI in Croatia. It would be useful to implement an adequate drought monitoring system in the Sinjsko polje in order to quantify groundwater and soil moisture, which are crucial for agricultural conditions. The role and importance of this karst field in the agricultural, social and economic terms is important not only for the town of Sinj, but also for the entire region. The effort, results and ideas presented in this work are encouraging, and point to the need for conducting further research so as to obtain information that can be useful for proper management of soil and water in the Sinjsko polje.

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