Dynamics of meteorological and hydrological droughts in the Neman river basin

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Abstract
The analysis of drought dynamics in the Neman river basin allows an assessment of extreme regional climate changes. Meteorological and hydrological warm period droughts were analyzed in this study. Meteorological droughts were identified using the standardized precipitation index, and hydrological droughts using the streamflow drought index. The whole river basin was analyzed over the period from 1961 to 2010. Precipitation data from Vilnius meteorological station (from 1887) and discharge data from Smalininkai (Neman) hydrological station (from 1811) were used for an evaluation of meteorological and hydrological drought recurrence over a long-term period. It was found that the total area dryness has decreased over the last 50 years. A statistically significant increase in standardized precipitation index values was observed in some river sub-basins. An analysis of drought recurrence dynamics showed that there was no indication that the number of dangerous drought was increased. It was determined that the standardized precipitation index cannot successfully identify the hydrological summer droughts in an area where the spring snowmelt forms a large part of the annual flow. In particular, the weak relationship between the indices was recorded in the first half of the summer, when a large part of the river runoff depends on accumulated water during the spring thaw.

Keywords: drought, precipitation, streamflow, meteorological drought, hydrological drought, SPI, SDI, Neman

1. Introduction
Every drought formation is a complicatedly defined process in terms of its active effect on the environment. A meteorological drought is strictly determined by the precipitation intensity, amount and distribution statistics. A hydrological drought can be defined as a long-term (decades, months etc) shortage of water income in a basin. The time frame for its formation depends on topography and land cover, water balance structure within the basin, etc. It is crucial to identify both—hydrological and meteorological droughts—in the river basin. Therefore, the world and Europe raise awareness of droughts’ impact on the natural environment (BACC 2008, Bordi \textit{et al} 2009), the socio-economic sectors (Thorsteinsson...
and Björnsson 2011), and on the political agenda (Kossida et al. 2009, European Commission 2012).

Following the Lincoln Declaration on Drought Indices (WMO 2009), WMO experts on hydrological droughts met in Geneva, Switzerland (2011) looking for a unified index. They agreed that there is still no one ‘perfect’ index determining hydrological drought because of the complexity of the phenomena (Hayes et al. 2011). There are various hydrological drought indices used in different parts of the world (Niemeyer et al. 2006, Nalbantis and Tsakiris 2009). SDI is analogous to the standardized precipitation index (SPI), which the WMO has declared an official meteorological drought index (WMO 2009). The relationship of the SPI and various hydrological drought indices opens up a wide range of applications and possibilities for its use (Vicente-Serrano and López-Moreno 2005, Liu et al. 2012, Medved-Cvikl et al. 2012). The SPI is already used in the Baltic Sea region for determining drought periods (Rimkus et al. 2012b, Valiukas 2012).

Droughts have a lot of definitions and characterizations. The Neman river basin lies under humid temperate climate conditions (Gailiušis et al. 2001, Galvonaitė et al. 2007) and cannot experience such water shortages as it is in the tropical and mid-latitudinal arid regions. Our identified dry period and periods of low streamflow could be interpreted as droughts because of the impact on wildlife and the socio-economic sectors. The river basin faces a decrease in yield extent, a reduction in overall agricultural productivity, a massive increase in wildfires, an intensification of tree defoliation, a fall in water level of under the environmental discharge level, etc in 1992, 1999, 2002 and 2006 (Buitkuvienė 1999, Pauliukevičius 2004, Šapolaitė and Skulskis 2008, Ozolincius et al. 2009).

Transboundary waters are very important in the United Nations Economic Commission for Europe (UNECE). Their basins cover more than 40% of the UNECE region and more than 50% of the population lives here (UNECE 2011). The Neman river basin has very different natural, socio-economic and political features (Nilsson and Langaas 2011), and drought identification methods, data availability and formats vary a lot in different regions of the basin. The minimum runoff was reviewed by Gailiušis et al. (2001), and hydrological droughts were analyzed by Kriauciūnienė et al. (2008) in the Lithuanian part of the Neman basin. The complexity and regional differences of droughts can be deduced using various identification methods (Prudhomme and Sauquet 2007, Nalbantis and Tsakiris 2009, Fleig et al. 2011).

The main goal of this research is the identification of meteorological and hydrological drought dynamics in the transboundary Neman river basin. Trends from 1961 to 2010 of the SPI and SDI were analyzed. We stated that not only SPI, but also SDI could be used in the identification of long-term dry periods. Spatial clustering of the basin was carried out for the SPI and SDI dynamics. The clustering revealed that the drought dynamics in the Neman river basin have the same tendencies using SPI and SDI, even though the extreme values of indices differ in their persistence. Also, long-term changes of the SPI (from 1887 to 2012) and the SDI (from 1812 to 2012) were identified for the first time in the Neman river basin. Additionally, the correlation between the SPI and SDI and its changes throughout the year was assessed. The experience collected and the results from drought identification can be used in other basins with the same runoff regime, i.e. in lowlands, and relatively large, snow and groundwater dominated temperate climate river basins. The comparison of the SPI and SDI indices allows the recognition of regional differences for drought formation and simplifies the drought identification process using monthly data instead of daily sets. This message is very important for all transboundary river basins (with variability in data formats, time series length, etc) and rivers with long datasets. The findings lead to a better understanding of the relationships between meteorological and hydrological droughts dynamics, regionalization, and dataset applicability.

2. Short description of the Neman basin

Neman is one of the largest European rivers (figure 1). It is 14th according to its length (937.4 km) and 15th according to its catchment area (97 864 km²). The Neman catchment is situated in five countries: Lithuania (47.7% of the catchment area), Belorussia (46.4%), Russia (3.2%), Poland (2.6%) and Latvia (0.1%) (Gailiušis et al. 2001).

The Neman basin is dominated by coniferous forests. Forest covers about 35% of the catchment area. About 1.5% of the basin area is covered by lakes. Swamps, bogs and wet forests cover about 20% of the basin area (Povilaitis et al. 2011).

The annual precipitation in Neman basin varies from 550 to 900 mm and the annual evaporation is from 450 to 600 mm (Galvonaitė et al. 2007, Respublikanskyj Hydrometcentr 2009). Due to an excess in precipitation the annual runoff volume from the basin is relatively large ∼25 km³.
The largest variation of climatic conditions in the Neman basin depends on the distance from the Baltic Sea (Galvonaitė et al. 2007). One of the largest effects of proximity to the sea is the ratio of liquid precipitation during winter (Kriauciuniene et al. 2006). In the western part of the Neman basin the ratio of liquid precipitation is higher; the winter temperatures are higher and snow cover is thinner. Due to this the spring floods are lower in the western part of the Neman basin than they are in the rest of the basin.

The tendencies of mean annual runoff changes during the period 1961–2010 vary in the different parts of the Neman basin. The positive changes prevail in the northern part of the basin, while the negative changes are more common in the southern part. However the annual runoff trends during the period 1961–2009 are not statistically significant ($p < 0.05$) (Rimkus et al. 2012a). More significant is the seasonal runoff redistribution. The greatest changes were observed in the first part of year. In January and February the runoff has increased in all the rivers in the Neman basin. This increase can be related to the increase in the amount of precipitation during these months, and due to an increase in the winter temperature (Stonevičius et al. 2012). The winter temperature increased by 2.8 °C during the investigation period in the Neman basin. This higher winter temperature leads to more frequent thaws (Gečaitė and Rimkus 2010) and to a change in the composition of the precipitation. Liquid precipitation has begun to prevail during the winter in the last few decades. As a consequence, the water content of the snow cover at the end of winter has decreased in the Neman basin. This factor, and the fact that the air temperature of March has also increased significantly (by 2.3 °C on average), leads to earlier melting of the snow cover. A decrease in the number of days with snow cover during the 50-year period was also observed. In some locations the changes are statistically significant. In the first half of the investigated period, snow often covered the major part of the basin area during a large part of March, while in recent years, due to earlier melting of the snow cover, such cases are quite rare (Rimkus et al. 2012a). The thinner snow cover and smaller amount of water in it at the end of the cold season may be the main reason why the maximum flood runoff has decreased in all the rivers in the Neman basin. Due to the shift of the spring flood end date, the runoff in April and May decreased during the period 1961–2009 in most of the Neman basin. In June the changes in runoff gradually shifted from positive in the north to negative in the south, but the magnitude of changes were relatively small. In July, August and September the changes remained very small; however the rise in runoff prevailed in these months during the period 1961–2009 (Stonevičius et al. 2012).

The Neman basin has very large resources of deep groundwater; consequently the industry and municipalities usually use only groundwater (Paukštys 2011). The largest anthropogenic factor which can affect the runoff is artificial regulation. There are more than 800 reservoirs larger than 5 ha in the Neman basin, but only 6% of them are larger than 50 ha (Jablonskis and Tomkevičienė 2004, Kirwiel 2007). Previous studies show that reservoirs smaller than 50 ha have a very insignificant effect on the warm season runoff (Kirwiel and Kukshinov 2007). The total volume of all the reservoirs in the Neman basin produces only 5% of the Neman annual runoff (Gailiūsis et al. 2001); consequently the reservoirs used for hydropower production work on a daily regime. Even the large reservoirs (up to several hundreds of hectares) have here only a small effect on the warm season runoff. Studies show that the warm season runoff is reduced by 0.3–1.2% by these reservoirs (Gailiūsis and Kriauciuniene 2009).

The largest reservoir in the Neman basin is the Kaunas HPS reservoir (area 6350 ha, active volume 222 million m$^3$, built in 1960). In the warm season, this reservoir usually operates on a daily regime (Gailiūsis et al. 2000). Previous studies show that the variability of warm season runoff in Neman is mostly affected by natural factors rather than the anthropogenic ones (Jablonskis 1992, Gailiūsis et al. 2001); however one of the most significant dry periods had just ended in 1960, when the Kaunas HPS was built. The relationship between the 1945–2009 cumulative sums of monthly runoff normalized by mean in Smalineikai HS (downstream Kaunas HPS) and in Druskininkai HS (upstream Kaunas HPS) shows that there was no noticeable brake point in 1960 (figure 2). This means that the warm season runoff in both cross sections was formed according to the same factors, and the end of the dry period in 1960 is not likely to be related to Kaunas HPS activity.

### 3. Data and methods

Precipitation and runoff data from the meteorological and hydrological stations located in Lithuanian and Belorussian part of the Neman river basin were used in this study. The analyzed period covers 1961–2010. Monthly precipitation data was received from 21 meteorological stations (13 in Lithuania and 8 in Belarus) (figure 1). For the purpose of assessing the dynamics of meteorological droughts over a longer period of time we used precipitation data from Vilnius meteorological station. This station has the longest set of data (from 1887) in the basin area.

The location of Vilnius MS has changed several times since 1887. The homogeneity of monthly precipitation datasets in this station was tested using a $t$-test. Inhomogeneity was not detected during this analysis. The locations of the other investigated stations have remained almost unchanged since 1961. Changes in the stations’ environment can have only a small impact on data quality because the majority of the stations are in small cities (often outside urban areas). More important are instrumental and methodological changes in the basin area during the investigation period. The Tretyakov precipitation gauge shield replaced the Nipher shield in 1952 in Vilnius. For this reason the precipitation data until 1952 was corrected. Correction coefficients were applied for the December–March period, and varied from 3 to 5%. To compensate wet loose on the gauge walls, wetting corrections were introduced to the gauge readings in the whole former Soviet Union territory in 1966. Therefore, the monthly precipitation sums prior to 1966 were adjusted using wetting corrections, which varied from 5 to 15% for different months (Hydrometeorological Centre of Lithuania 1991).
The analysis of hydrological drought recurrence in the Neman basin area was based on data from 15 hydrological stations (7 in Lithuania and 8 in Belarus). These hydrological stations are located on different independent small and medium-sized rivers and the upper reaches of large rivers (figure 1, table 1). Long-term hydrological drought trends were calculated using the Neman on Smalininkai (catchment area 81,200 km$^2$) data. This hydrological station has been in operation since 1811. Because the station is only 111 km from the mouth of the Neman (figure 1), it is likely that its data accurately reflects the total basin drought trends.

For the analysis of meteorological droughts the standardized precipitation index has been used. This index is recommended by the WMO for meteorological drought identification. An index to evaluate a precipitation deficit was suggested by McKee et al. (1993). Only monthly precipitation totals are used for SPI index calculation. The calculation of SPI is less complex than the other indices (such as the Palmer severity drought index), so data from a larger number of stations can be used for regional drought analysis. Initially, the variability of precipitation totals is described by gamma distribution, and then transformed to a normal distribution (McKee et al. 1993, Edwards and McKee 1997). If the SPI value is less than −1 a drought is recorded. The lower the value, the more intense the droughts identified (table 2). The SPI index value is calculated for different time steps (from 1 to 60 months). For the SPI1 calculation only one month of precipitation is used, while for the SPI3 calculation the total precipitation of three consecutive months is required. The SPI3 index reflects well the short and medium-term moisture conditions, and is widely used to identify meteorological drought (Sepulcre-Canto et al. 2012). In this study, SPI3 values were recorded for June–September. The SPI index was calculated using the SPI index calculator distributed by The National Drought Mitigation Center (USA).

Hydrological droughts in this work were evaluated using the streamflow drought index (SDI). The index developed by Nalbantis and Tsakiris (2009) shows the standardized cumulative streamflow volume over 3, 6, 9 or 12 consecutive
It was proposed to calculate the total monthly discharge starting from the beginning of the hydrological year (i.e. November). However, in the Neman basin a large part of the annual water volume flows during the spring snowmelt and measuring the discharge starting from November does not allow a correct assessment of the hydrological conditions during the warm period of year. In this paper, the SDI was calculated by calculating the three-month average discharge. The river runoff time series due to natural integration has serial dependence, therefore the SDI values for the adjacent months are highly correlated. Only non-overlapping 3-month SDI values were used to analyze long-term hydrological drought dynamics. The dryness of the first part of the warm period was calculated as a standardized total of the average discharge over three consecutive months from May to July; meanwhile, the second part of the warm period was evaluated as a total of the August–October period.

Small river discharge distribution is asymmetrical. In this study it was considered that the discharge distribution is a two-parameter log-normal, so the values were normalized. An interpretation of the SDI values is presented in table 2.

A hierarchical complete linkage method (Romesburg 1984) was used for the purpose of dividing the Neman basin area into different parts with specific precipitation and river flow. The area was divided into four clusters with differing SPI or SDI index dynamics.

Sen’s slope method was used for linear trend value calculation (Helsel and Hirsch 1992). The statistical significance ($p < 0.05$) of the observed trends was evaluated using the non-parametric Mann–Kendall test.

4. Results

4.1. Meteorological droughts

The results show that during the investigation period the estimated SPI3 value increased in the whole Neman basin during the warm season (figure 3). The SPI3 calculated for June is unchanged (figure 3(a)). Meanwhile, the SPI3 estimated for July and August shows a clear upward tendency. According to the Mann–Kendall test a statistically significant ($p < 0.05$) trend was observed in August (figure 3(b)). Positive, although in most cases statistically insignificant, SPI3 trends were recorded in almost all the analyzed sub-basins during the warm period. Only in some sub-basins (Jūra and Minija) located in the western part of the territory did the SPI3 values remain almost unchanged.

Using cluster analysis the Neman basin has been divided into four clusters according to SPI3 index values and SPI3 index dynamics investigated in different parts of the basin (figure 4). The changes in the western part of the basin were the smallest. There the largest precipitation amount was recorded and drought conditions remained almost unchanged. Statistically insignificant index values increased during the whole observed warm period in the eastern part of basin. Meanwhile, in the south and the central part of the basin a statistically significant increase in the index value in July was recorded from 1961 to 2010. Also, a statistically significant index increase was observed in the upper reaches of the Neman basin in August. In June, the western and south-western part of the basin recorded an insignificant tendency towards an increase in dryness.

To assess the dynamics of the SPI3 index over a longer period of time, Vilnius precipitation data from 1887 has been used in this study. It is the longest precipitation set of data in the basin. The linear correlation coefficient calculated between the SPI3 index value in Vilnius and in the entire basin for the period from 1961 to 2010 ranges from 0.82 (June) to 0.91 (July). So the SPI3 index calculated for Vilnius may well represent dry and wet conditions for the whole territory.

There were unequal tendencies of SPI3 dynamics in separate parts of the warm season from 1887 to 2012 in Vilnius. SPI3 index values in the first part of the warm period increased, while they decreased in the August and September (the changes were not statistically significant). This is the opposite trend from that recorded over the entire Neman basin since 1961. At the beginning of the warm period, lower than average values (more drought conditions) prevailed during the first half of the 20th century, while from the 1940s to the 1980s SPI3 index values were usually higher than average. Drought conditions during the second part of the warm period can also be split into several parts. By the third decade of the 20th century close to average conditions dominated, then a wet period continued for four decades. More frequent dry periods were recorded during the last few decades of the 20th century.

The number of cases when SPI3 index values dropped below −1 (drought conditions) in Vilnius was analyzed in
Figure 4. The Neman basin divided into clusters according to SPI3 index dynamics and trend values calculated for the June–September period in the different parts of the basin. The highlighted columns indicate statistically significant ($p < 0.05$) trends.

Figure 5. The number of cases in Vilnius when the recorded SPI3 index values were lower than −1 (drought conditions) in different decades from 1891 to 2010.

During the study period, extreme droughts (SPI3 < −2) were recorded 3 times. In 1964 and 1992 one was observed in the second half of summer, meanwhile in 1979 there was one at the beginning of summer. The most intense drought was in 1992, when extreme drought criteria were reached in all the analyzed sub-basins. In the Schara sub-basin the SPI3 index value dropped to −3.08. In August 1992, the SPI3 value calculated for the entire Neman basin was the lowest over the period 1961–2010 (−2.7).

4.2. Hydrological droughts

According to Smalininkai hydrological station data (which represents integrated runoff in most of the catchment (figure 1)), hydrological dryness slightly increased in the Neman basin from 1812 to 2012. The SDI3 calculated for July trend is negative and statistically significant ($p < 0.05$). The trend of SDI3 calculated for October is also negative, but statistically insignificant. Almost all hydrological moderate droughts (SDI3 < −1) were in the 20th century (figure 6). Very dry conditions at the beginning of warm season were from 1911 to 1960. In this period 36% of the SDI3 calculated for July values were less than −1. According to SDI3 values there were two events of extreme droughts (SDI3 < −2) at the beginning of the warm season in 1915 and 1921 (figure 6(a)). The second part of the warm season was driest at the beginning of the 20th century and from 1963 to 1976. During this 14 year period moderate hydrological drought conditions were observed 8 times (SDI3 < −1) (figure 6). The general SDI3 dynamics in the 20th century were similar to the SPI3.

All 15 independent sub-catchments were grouped into 4 clusters according to the dynamics of the SDI3 from 1961 to
Figure 6. The dynamics of the SDI3 values were calculated for July (a) and October (b) according to the Neman Smalininkai HS data from 1812 to 2012. Trends and slope values calculated using Sen’s method. The dashed line indicates the threshold of moderate hydrological drought (SDI3 $<-1$).

Figure 7. Clusters of sub-catchments grouped according to SDI3 dynamics.

2010 (figure 7). The location of the SDI3 and SPI3 clusters (figure 4) had a similar pattern.

Usually a hydrological drought spans only a part of the Neman basin. The longest dry period according to the SDI3 in the Neman basin was at the beginning of the study period from 1961 to 1976 (figure 8). Only in the sub-catchments of the 2nd cluster dry spells were infrequent. During the 1961–1976 period, a moderate hydrological drought in the 2nd cluster was observed only 4 times in the Isloch river, which is located closest to the 1st cluster of the river sub-basins. In the same 1961–1976 period the whole warm season was dry in the sub-catchments of the 1st and 3rd clusters. A moderate drought at the beginning of the warm season in the 4th cluster was frequent in the 1961–1975 period, but the end of the warm season was very dry only four years from 1968 to 1971.

At the end of the warm season, the largest part of the Neman basin was covered by a moderate hydrological drought in 1969 (80% of sub-catchments) and 1976 (67%) (figure 8). The most extreme hydrological drought was also at the end of the warm season of 1969. In the Svisloch, Merkys and Minija rivers the SDI3 calculated for October was lower than $-2$ (extreme drought), and in the majority of other sub-catchments moderate hydrological drought was observed.

From 1977 to 1999, hydrological droughts were rarer, and their spatial extent was smaller. The second dry period according to the SDI3 in the Neman basin was from 2000 to 2002. The beginning of the warm season was very dry in the 1st, 2nd and 3rd clusters. The end of the warm season was dry only in 2002, when moderate to extreme drought conditions occurred in two-thirds of sub-catchments in all four clusters.

During the extreme meteorological droughts of 1964 and 1992, the moderate hydrological droughts occurred only in...
half of the Neman basin sub-catchments. In the majority of meteorological stations the beginning of the 1979 warm season was extremely dry, but there were not even moderate hydrological droughts in any of the sub-catchments.

5. Discussion and conclusions

The derived drought periods using SPI and SDI indices fully correspond to extreme event definitions. There is a lot of evidence and proof that dry periods have a serious impact on wildlife and the socio-economic sectors in the Neman river basin. Previous research shows a decrease in various species of cultivated plant yields (Kulikauskas and Sprainaitienė 2005, Jundulas et al 2009) and in overall agricultural productivity (Šapolaitė and Skulskis 2008) during droughts. In 1992 the harvest was 30% below the average (Buitkuvienė 1999), and the same situation occurred in 2002 (Šapolaitė and Skulskis 2008). The drought effects are obvious in forest ecosystems. Drought periods slow down the radial growth of trees (Vitas 2004). Also, dry periods significantly reduce the cover of ground vegetation and increase crown defoliation (Ozolincius et al 2009). Most wildfires occur during drought periods (Buitkuvienė 1999). In 2006 just in Lithuania 1545 wildfire events were registered and losses reached more than €5 300 000. Dry conditions defined using the SPI and SDI have a direct effect on groundwater level and small river runoff (Pauliukevičius 2004). Extremely low values of SDI in the Neman river basin in 1969, 1976, 2002 and 2006 events correspond to a negative anomaly of river discharge in the entire Eastern Baltic region (Kriauciuniene et al 2012).

The dynamics of the SPI could be a primary source for the identification of meteorological drought trends in the Neman catchment. The SPI index trends over the last fifty years (1961–2010) show a slight decrease in dry conditions in most parts of the catchment. The results correspond with other research in Europe (Kjellström and Ruosteenoja 2007, Bordi et al 2009, Rimkus et al 2012b). SPI trends are determined by changes in the amount of precipitation in the Neman basin. Decreasing trends of dryness in the most parts of the catchment correspond with a rise in extreme precipitation events (Rimkus et al 2011). SPI values do not show trends only in western part of the catchment, which is characterized as the wettest region (Galvonaitė et al 2007), and liquid precipitation prevails in water input (Kriauciuniene et al 2006). Also, the research revealed that the regional difference of SPI dynamics match SDI dynamics (location of SPI clusters are very close to four sub-basin clusters)—usually the SPI index was used for meteorological drought identification, while there is a possibility to identify hydrological drought using different SPI time steps (Lloyd-Hughes and Saunders 2002).

Nalbantis and Tsakiris (2009) present high linear regression coefficients between the SPI and SDI. Also high correlations between the SPI and other hydrological drought indices were found by Vicente-Serrano and López-Moreno (2005), Liu et al (2012) and Medved-Cvikel et al (2012). Small river basins in mountainous areas with precipitation-dominant runoff prevailed in these studies, while our research does not show such a high correlation between the SPI and SDI. The Neman basin and its sub-basins are characterized by winter snow cover formation and high floods in spring. It does not allow the use of large time scale SPI values which are highly correlated with hydrological droughts (Vasiliades et al 2011). Moreover, the relationship between SPI and SDI values tend to change with seasons. At the beginning of the warm season, spring flood conditions play the most significant role in determining the occurrence of hydrological droughts in the Neman basin, while later in the year precipitation totals begin dominating as the main factor for drought formation (figure 9). The relationship between the SDI and the spring flood discharge (figure 9) depends on the climate and hydrology of the particular basin, and may assist in evaluating the suitability of the SPI to indicate hydrological droughts in this basin.

An analysis of the number of cases when drought conditions, according to the SPI3, have also been identified according to the SDI, showed a concurrence of only one out of 4 times at the beginning of the summer. The highest recurrence of similarity between the SPI and SDI was observed in August and September. A concurrence of droughts indicated by both the SPI and SDI varies from 26.6% to 62.5% depending on the sub-basin. Only in the western part of the basin does a recurrence of similarity between the SPI and SDI rise throughout the year, and reaches its maximum in October (>80%). In the western part of the Neman basin the concurrence ratio is higher than in the eastern sub-basins. The high ratio of the concurrence of hydrological and meteorological droughts can be related to the runoff formation conditions in different sub-basins. The percentage of surface runoff in total river runoff is higher in the western sub-basins; consequently the river runoff is more sensitive to rainfall than in the eastern sub-basins, where the groundwater contribution to runoff is higher.

An analysis of long-term changes in the SPI (using Vilnius MS data from 1887) and the SDI (using Smalininkai HS data from 1811) shows that both indices have similar fluctuation phases. This analysis shows that the amount of precipitation is the main factor for long-term dry and wet periods, and could be used for long-term hydrological dry period identification in the Neman river basin.
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