water

MDPI

Article

The Development of a Hydrological Drought Index for Lithuania

Serhii Nazarenko [1], Jūratė Kriaučiūnienė [1,*], Diana Šarauskienė [1] and Arvydas Povilaitis [2]

[1] Laboratory of Hydrology, Lithuanian Energy Institute, 44403 Kaunas, Lithuania
[2] Department of Water Engineering, Vytautas Magnus University, 44248 Kaunas, Lithuania
* Correspondence: jurate.kriauciuniene@lei.lt; Tel.: +370-3-740-1962

Abstract: Recently, the number and intensity of hydrological droughts have been increasing; thus, it is necessary to identify and respond to them quickly. Since the primary hydrological data in Lithuania are water levels, and converting these data into discharge takes additional time, there is a need to develop a methodology or adapt these data to analyze and detect hydrological droughts. This paper examines the concept of the standardized water level index (SWLI) calculation, which is based on the standardized precipitation index (SPI) and streamflow drought index (SDI) methods. SDI and SWLI data were compared; SWLI was used to analyze the situation in the past and future. A total of 15 main sub-basins were considered, and the future discharge of three rivers was estimated; SWLI showed good compatibility with SDI. To better analyze droughts, the use of severe drought threshold values (SDTV) was suggested as some river data (especially those for small rivers) needed to be corrected due to dense riverine flora. The dry years and trends identified by SWLI are consistent with previous studies.

Keywords: hydrological droughts; Lithuanian rivers; HBV model; SWLI; SDI; trends; projections

check for updates

Citation: Nazarenko, S.; Kriaučiūnienė, J.; Šarauskienė, D.; Povilaitis, A. The Development of a Hydrological Drought Index for Lithuania. *Water* **2023**, *15*, 1512. https://doi.org/10.3390/w15081512

Academic Editor: Leonardo V. Noto

Received: 31 January 2023
Revised: 11 April 2023
Accepted: 11 April 2023
Published: 12 April 2023

1. Introduction

Most European countries are considered to have sufficient water resources; however, water scarcity and droughts are increasing and spreading. From 1980–2020, the total economic loss from weather- and climate-related events was EUR 450–520 billion (in 32 countries of the European Economic Area [1]). Climate change, global warming and human activity may unprecedentedly exacerbate the problem of drought [2–4].

Even among drought experts, there is no single definition of drought that everyone would agree on [5–7]. Water Directors within the CIS (a Common Strategy for the implementation of the Water Framework Directive) process have decided on the following definition of drought: it is a temporary, negative and severe deviation along a significant period and over a large region from average precipitation values (a rainfall deficit), which may lead to meteorological, agricultural, hydrological and socio-economic drought, depending on its severity and duration [8]. Water deficit typically propagates through the hydrological cycle, impacting different ecosystems and human activities accordingly [9].

Accomplished studies challenge the view that hydrological drought can only be described as a lack of precipitation and show many gaps and uncertainties in our knowledge of this extreme event. A number of interrelated phenomena may cause hydrological drought [10,11]; many efforts are being made to study the various aspects of droughts and aim to provide early warning and information to decision-makers, policy-makers, water managers, water users and the general public about droughts. To prevent or at least mitigate the effects of a drought, it is necessary to understand this phenomenon, identify its signs as quickly as possible and prepare for a drought's impact [12–14].

Scientists have developed numerous methods to identify hydrological drought. Criteria for identifying an impending hydrological drought and its beginning or end can include the simplest indicators (e.g., river or groundwater level, flow rate) or complex drought indices (e.g., aggregate dryness index, palmer hydrological drought severity index, surface water supply index) that require several or more indicators. When managing drought, it is convenient to use indices to reduce the complex problem to one single number. However, water managers should be cautious in choosing indices [6,15]. It would be beneficial to develop a composite drought index that integrates all relevant data and drought descriptions, considering the predominant types of droughts in time and space and climate change scenarios [16]. However, a recent report published by the Intergovernmental Panel on Climate Change [4] warns that droughts are a complex and difficult-to-predict natural phenomenon, and that differences between drought types are not unambiguous and cannot be described by a single universal definition or directly measured by a single variable. The National Meteorological and Hydrological Services around the world are encouraged to use the standardized precipitation index (SPI) to characterize meteorological drought; however, a comprehensive indicator to describe agricultural and hydrological droughts still needs to be proposed [17].

Although Lithuania belongs to a humid continental climate, the drought phenomenon is quite well known. The recent dry and warm summers are causing major changes in river runoff. For three consecutive summers of 2018–2020, a hydrological drought for the entire country was declared. Although scientific studies based on available observational data do not reveal clear trends in rising dryness and extreme droughts [18,19], end-of-century climate change may enhance the likelihood of more intense and frequent meteorological droughts, which may increase the threat of hydrological droughts [20,21]. Rising warm-season temperatures and consequent increasing evaporation are likely to have a particular impact on runoff during the warm season, which is a critical time for water users and aquatic ecosystems, even under normal climatic conditions. With the growing evidence of climate change, Lithuanian scientists have been paying closer attention to droughts in recent years. The meteorological effective drought index (EDI) proposed by Byun and Wilhite [22] was used to identify hydrological drought during the warm period [23]. A study of drought dynamics during the warm period of the year using the meteorological standardized precipitation index (SPI) proposed by McKee et al. [24] and the hydrological standardized water level index offered by Nalbantis and Tsakiris [25] was carried out [19]. The suitability of the hydrological standardized runoff index (SRI) proposed by Shukla and Wood [26] to determine hydrological drought was also investigated [27]. The ability of the analyzed indices to identify hydrological droughts in Lithuanian rivers mainly depended on the nature of river feeding, e.g., some indices performed better on groundwater-fed rivers and others on snowmelt-fed rivers. To our knowledge, thus far, only one scientific study has been devoted to assessing hydrological drought in Lithuania using river water levels [28]. This study aimed to identify the warm-period hydrological drought cases in Lithuania using the streamflow drought index (SDI; calculated based on discharge data) and standardized water level index (SWLI; calculated based on water level data) to compare and evaluate the possibilities of their practical application. The findings based on data from seven rivers (eight water gauging stations) revealed that a modified SDI methodology based on water level data (i.e., SWLI) could become a good alternative for detecting hydrological droughts in Lithuania.

As the operational information of the hydrology network in Lithuania consists of (hourly) water level data, it should be used to characterize the hydrological drought and declare the state of severe hydrological drought. Such an assessment has a significant advantage. Water levels can be easily measured directly, while discharge is estimated indirectly from the water level using a water level-discharge ratio. This study aimed to analyze the past conditions of hydrological drought and project future drought scenarios for the entire territory of Lithuania based on its major sub-basins using the improved methodology for calculating the standardized water level index (SWLI).

2. Materials and Methods

2.1. Study Area and Data

Lithuania is located on the eastern coast of the Baltic Sea. It covers an area of 65,200 square kilometers and is the largest and southernmost of the three Baltic States. It is a country of plains (the highest point being 294 m above sea level) with more than 22,000 rivers and rivulets having a total length of over 77,000 km [29]. According to the Köppen-Geiger climate classification, Lithuania belongs to a humid continental climate. It falls into the water surplus zone as the annual ratio of precipitation to evaporation is 1.47. The annual river runoff varies from 4.2 to 14.0 L/(s·km^2) and depends on the distance from the sea, topographic features, catchment morphology, lithology, underground feeding patterns, etc. The Nemunas River is a major Lithuanian river. It is 937 km long and drains approximately 98,000 square kilometers (46,600 km^2 belongs to Lithuania and comprises 72% of its territory). Its average multiannual discharge at Smalininkai is 540 m^3/s. The longest and largest Nemunas tributaries in Lithuania (in terms of catchment area) are Šventoji, Neris, Nevėžis, Šešupė, Merkys, Jūra and Minija. Typically, the annual hydrograph of the Lithuanian river consists of the peak discharge in early spring, indicating the maximum amount of water in the river bed due to spring snowmelt flooding; additional, less significant peak discharges (due to flash floods) may be observed in late summer or autumn, but the discharge remains mostly low throughout the warm period. In the warm period, in the small rivers and streams, the phenomenon of flow intermittency can be observed under certain physical-geographical conditions. It was estimated that the maximum duration of flow intermittency could range from 6 to even 152 days [30].

The study of the hydrological drought was based on streamflow records from 15 river catchments (Figure 1). These rivers were chosen to represent the main sub-basins of Lithuania because (i) they are semi-natural (i.e., the least anthropogenically affected), (ii) they have 30 years (1991–2020) of observational data series, and (iii) their discharge data (based on the stage-discharge curve, Q-H) are the most accurate and reliable in the sub-basin. The list of selected rivers and their gauging stations is given in Table 1. The above data were received from the Lithuanian Hydrometeorological Service (LHMT). Monthly precipitation and air temperature data from the observational period of 1991–2020 needed for modeling were also obtained from LHMT.

Table 1. List of the studied water gauging station (WGS) catchments and their main characteristics (1991–2020).

№	River	WGS	Abbreviation	Sub-Basin	WGS Catchment Area, km^2	Qav *, m^3/s	Q30 **, m^3/s	Qav/Q30
1	Nemunas	Smalininkai	Nem-Sma	Nemunas and its small tributaries	81,200	479.9	259.3	1.85
2	Merkys	Puvočiai	Mer-Puv	Merkys	4300	32.1	21.8	1.47
3	Neris	Jonava	Ner-Jon	Neris and its small tributaries	24,600	162.6	89.6	1.81
4	Žeimena	Pabradė	Zei-Pab	Žeimena	2580	20.2	11.9	1.70
5	Šventoji	Ukmergė	Sve-Ukm	Šventoji	5440	41.1	16.3	2.52
6	Nevėžis	Panevėžys	Nev-Pan	Nevėžis	1090	6.1	1.1	5.55
7	Dubysa	Lyduvėnai	Dub-Lyd	Dubysa	1070	8.2	1.9	4.32
8	Mituva	Žindaičiai	Mit-Zin	Mituva	403	2.6	0.1	26.00
9	Šešuvis	Skirgailai	Ses-Ski	Jūra	1880	14.7	2.3	6.39
10	Minija	Kartena	Min-Kar	Minija	1230	16.7	2.7	6.19
11	Svyla	Guntauninkai	Svy-Gun	Dauguva	148	0.9	0.023	39.13
12	Nemunėlis	Tabokinė	Nem-Tab	Nemunėlis	2690	20.2	2.9	6.97
13	Mūša	Ustukiai	Mus-Ust	Mūša	2280	10.1	1.3	7.77
14	Venta	Leckava	Ven-Lec	Venta	4060	28.2	4.4	6.41
15	Bartuva	Skuodas	Bar-Sku	Lithuanian coastal rivers	612	7.1	0.6	11.83

Notes: * Qav—average discharge for 30 years (1991−2020). ** Q30—average of annual 30-day minimum discharge in the warm period (1991–2020).

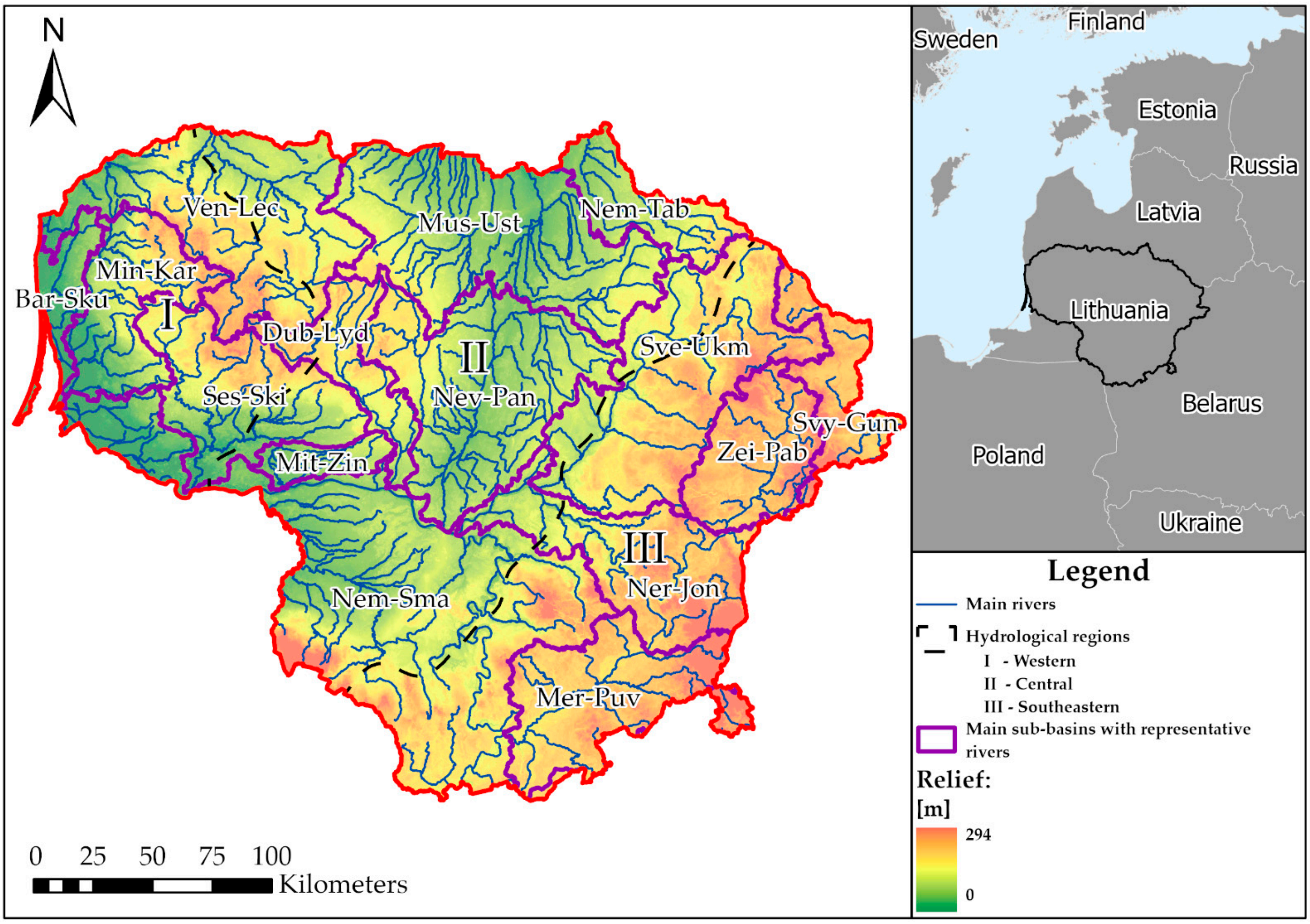


Figure 1. Fifteen main river catchments of Lithuania used in the analysis.

2.2. Methods

2.2.1. Calculation of Hydrological Drought Indices

The standardized water level index (SWLI) proposed by [28] and streamflow drought index (SDI) developed by Nalbantis and Tsakiris [25] were used to identify hydrological droughts in Lithuanian rivers. These indices are based on the measured water level (SWLI) and discharge (SDI) values. Since these indices are based on the SPI calculation methodology, the minimum time period for calculation should be identical. For SPI, it is 30 years [24]. According to this, we used the same minimum period. A drought of a relevant magnitude is recorded when the index value is lower than −1.0 [15]. The essence of indices is that they calculate anomalies of a certain magnitude (of water level or discharge) over a selected period based on a comparison of that magnitude using data from a long-term period. As an input, daily water level and discharge data were used; a 10-day accumulation period was also selected.

SWLI and SDI were calculated as follows:

$$SWLI = \frac{H_{i,j} - H_j}{\sigma_{j(H)}}, \tag{1}$$

$$SDI = \frac{Q_{i,j} - Q_j}{\sigma_{j(Q)}}, \tag{2}$$

where $H_{i,j}$ and $Q_{i,j}$ indicate the water level and discharge for a given 10-day period, respectively, H_j and Q_j indicate the multiannual decadal values of the mean water level and discharge, respectively, $\sigma_{j(H\,or\,Q)}$ indicate the standard deviation of the multiannual mean

H_j or Q_j and i equals a period of 10 days. All received data were checked for normality and, for that, we devised data distribution histograms and calculated the Shapiro-Wilk test for smaller samples from the main data set; all results confirmed the data normality.

An index value below zero indicated hydrological drought. The state of hydrological drought is defined as follows: the average drought is when $-1.49 < \text{SDI} < -1.0$, severe drought is when $-1.99 < \text{SDI} < -1.5$ and extreme drought is when $\text{SDI} < -2.0$ [25]. Because SWLI and SDI values are indicated as standard deviations from the long-term mean, they can be used to compare anomalies over any period.

In operational work, to identify hydrological droughts, it would be more rational to use a standardized water level index (SWLI), which is calculated from directly measured water level values. Although discharge better describes the water content in rivers and their ecological conditions, it is determined indirectly from water level data. However, the drought estimated according to water levels must also match the actual water conditions as the drought indicated by discharge. Theoretically, the SWLI and SDI values must have a linear (1:1) relationship. Deviations from this relationship may be due to various processes taking place in the river bed (e.g., development of aquatic vegetation, bottom deformation, etc.); therefore, the relationship needs to be adjusted for objectivity. Thus, we could not use the usual scale to assess severe drought through the SWLI index.

To determine the extent to which the correlation curves of SWLI and SDI varied from linear dependence (y = x) in each river, calculations were performed by inputting an x-value (SDI coefficient) of −1.5 (this value represents the threshold for severe drought in the SDI index and theoretically should be the same for the SWLI index) into the equation of determination. According to this, the new severe drought threshold values (SDTV) were used for SWLI using equations of determination.

2.2.2. Preparation of Climate Change Models

To predict future drought trends, three regional climate models (RCM) were chosen for data preparation and analysis (Table 2). A more detailed description of the selection process of regional climate models suitable for the conditions of Lithuania is provided in a previous article [31]. The two most commonly used RCP scenarios (RCP4.5 and RCP8.5) [4] were applied to analyze drought evolution in the future.

Table 2. Main information about chosen RCMs.

№	Driving Model	RCM	Institute	Resolution	Ensemble
1	CNRM-CERFACS-CNRM-CM5	RCA4	SMHI	0.11°	r1i1p1
2	ICHEC-EC-EARTH	RACMO22E	KNMI		
3	MPI-M-MPI-ESM-LR	REMO2009	MPI-CSC		

The models mentioned above were extracted from the EURO-CORDEX database (www.euro-cordex.net (accessed on 21 October 2022)). Daily temperature and precipitation data were used to calculate river discharge. It was decided to use the quantile mapping method to adapt climate data to Lithuanian conditions [32,33]:

$$St^{Obs} = h(St^{CM\ RP}) = ECDF^{OBS-1}(ECDF^{CM\ RP}(St^{CM\ Fut})) \quad (3)$$

where St^{Obs} indicates the observed meteorological parameter, $St^{CM\ RP}$ indicates the climate model output for the reference period, $ECDF^{OBS}$ indicates the empirical cumulative distribution function for an observed period, $ECDF^{CM\ RP}$ indicates the empirical cumulative distribution function for the climate model reference period and $St^{CM\ Fut}$ indicates the meteorological parameter, which is modeled by the climate model for the future period [32,33].

2.2.3. Discharge Projections Using the HBV Model

The drought projections were made for three rivers using the HBV hydrological model. This software was created by the Swedish Meteorological Hydrological Institute (SMHI) [34]. HBV is a rainfall-runoff modeling technique applied to calculate the total water balance in a catchment. For the modeling process, it is necessary to specify the following characteristics of the watershed: total area of the watershed, area of territories covered by forests and under lakes, height above sea level, daily flow of rivers and daily values of precipitation and air temperature for the area in the simulated watershed [21]. The HBV model is based on the water balance equation [35]:

$$P - E - Q = \frac{d}{dt}[SP + SM + UZ + LZ + V], \quad (4)$$

where P indicates precipitation, E indicates evaporation, Q indicates discharge, SM indicates soil moisture, SP indicates snow-pack, UZ indicates groundwater zone, LZ indicates lower groundwater zone and V indicates lake or dam volume. The computations were carried out in three steps: (i) estimation of the amount of precipitation reaching the ground; (ii) estimation of slope runoff; and (iii) estimation of runoff in the watercourse and runoff transformation. For such a complex model, a data set of physical-geographical data from the CORINE database was also used for each river (Table 3). Their processing was performed using the ArcGIS software.

Table 3. Main characteristics of the selected river catchments.

River—WGS	Land Use Characteristic		
	Lakes, %	**Wetland, %**	**Forests, %**
Nemunas-Smalininkai	1.17	0.82	48.50
Žeimena-Pabradė	9.28	1.29	60.07
Šešuvis-Skirgailiai	1.07	0.69	23.21

Since the main task of this work was to study the drought of the warm period (May–October), the main emphasis during calibration was on the parameters responsible for the runoff formation in the summer period and the baseflow. In addition, 19 main parameters were used to calibrate the developed catchment-based hydrological models. Calibration was performed in the recommended order by the software developers [35]: volume parameters, snow parameters, soil parameters, response parameters and damping parameters. The primary focus was on parameters that directly impact warm-season runoff, such as maximum soil moisture storage (fc), percolation capacity (perc) and recession of summer and autumn discharge (khq, k4), among others. The suitability and quality of the developed hydrological models were confirmed by the strong correlation between the measured and calculated water discharges (r were higher than 0.7) (Table 4).

Table 4. Results of calibration and validation of hydrological models.

River—WGS	Calibration (1986–1995)			Validation (1996–2005)		
	r	**NSE ***	**RE, %**	**r**	**NSE**	**RE, %**
Nemunas-Smalininkai	0.84	0.706	−0.6	0.81	0.700	0.7
Žeimena-Pabradė	0.87	0.765	−5.7	0.81	0.717	3.2
Šešuvis-Skirgailiai	0.88	0.779	3.1	0.87	0.786	−0.8

Notes: * Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance compared to the measured data variance [36].

3. Results

Based on SDI and SWLI indices, 15 rivers with a 30-year data set (from 1991 to 2020) were selected for drought analysis. Additionally, three rivers were chosen for analysis in the near (2021–2060) and distant (2061–2100) future.

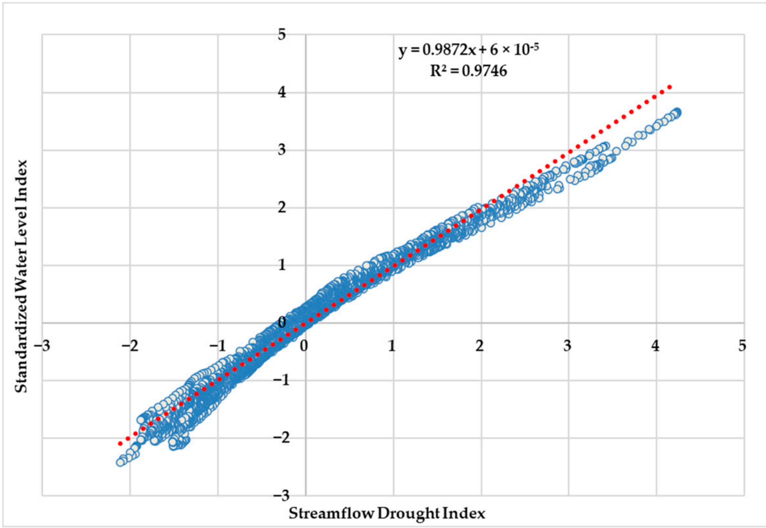
3.1. Assessment of the Suitability of SDI and SWLI in Lithuania

Based on the hydrological data of 15 water gauging stations (WGS) of Lithuanian rivers, the suitability of two selected hydrological drought indices—the standardized water level index (SWLI) and streamflow drought index (SDI)—was investigated. The values of these indices were expected to have a linear relationship (y = x), in which case, SWLI could be directly applied to identify hydrological droughts. All established linear equations had different coefficients and free terms, i.e., they indicated the absence of a clear linear relationship. The linear relationships (Figure 2) showed that the SWLI and SDI indices evaluated drought differently due to the differences in the range of negative values. Therefore, corrections were made to use the SWLI index to identify drought. The SWLI corresponding to the limit value of severe hydrological drought (according to SDI, i.e., when SDI = −1.5; Table 5) was calculated from the equations of the correlation curves between the mentioned indices in the studied rivers.

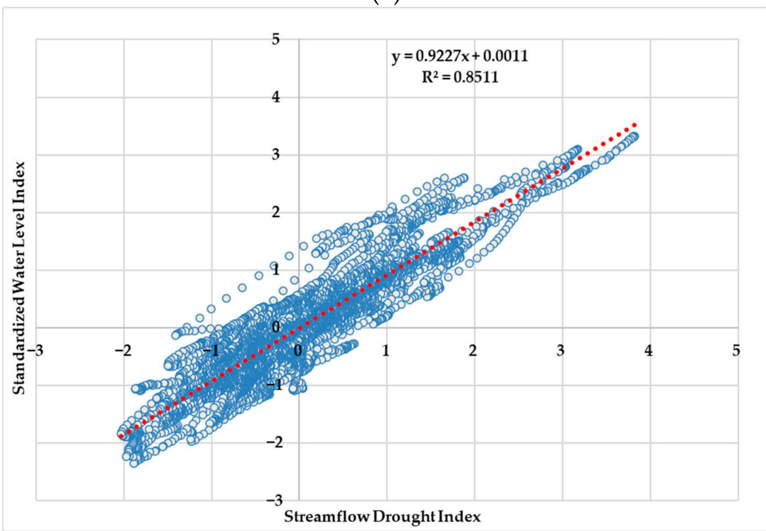
Table 5. Coefficients of determination between SWLI and SDI values; SDTV according to SWLI.

№	WGS	R^2	SDTV
1	Nem-Sma	0.97	−1.48
2	Mer-Puv	0.85	−1.38
3	Ner-Jon	0.95	−1.46
4	Zei-Pab	0.85	−1.38
5	Sve-Ukm	0.77	−1.32
6	Nev-Pan	0.89	−1.41
7	Dub-Lyd	0.82	−1.27
8	Mit-Zin	0.91	−1.40
9	Ses-Ski	0.92	−1.43
10	Min-Kar	0.91	−1.42
11	Svy-Gun	0.95	−1.41
12	Nem-Tab	0.90	−1.41
13	Mus-Ust	0.78	−1.32
14	Ven-Lec	0.91	−1.43
15	Bar-Sku	0.81	−1.34

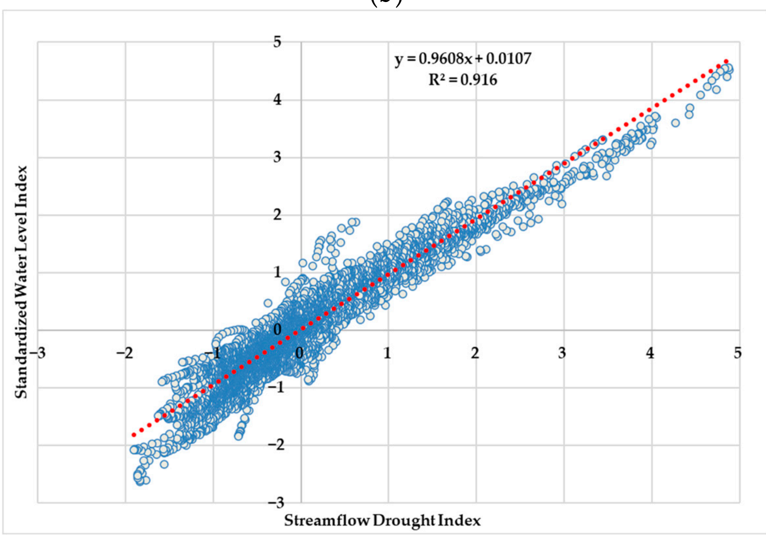
The number of dry events for each month was calculated. It was found that May had the highest number of severely dry days in Lithuania during the warm period. This trend was observed for seven out of 15 rivers investigated in Figure 3a. The greatest number of severely dry days over a 30-year period was also estimated in May, as shown in Figure 3b. October had the lowest number of severely dry days according to the SWLI (SDTV) index, and there were no significant changes during the June–September period. This distribution was caused by the physical-geographical and climatic characteristics of each individual sub-basin and the influences of other sub-basins, as in the cases of the Nemunas and Neris rivers. Figure 3c,d depict the distribution of severely dry days for the Nemunas and Žeimena rivers and provide the ratio of dry days between the two indices, SDI and SWLI. Although the SWLI index and SWLI with SDTV threshold indicated a higher number of severe drought events, the general trends persisted with SDI.



(**a**)



(**b**)



(**c**)

Figure 2. Relationships between SWLI and SDI with equations and coefficients of determination: (**a**) Nemunas-Smalininkai; (**b**) Žeimena-Pabradė; (**c**) Šešuvis-Skirgailiai. The red dotted lines represent the trend lines for data set.

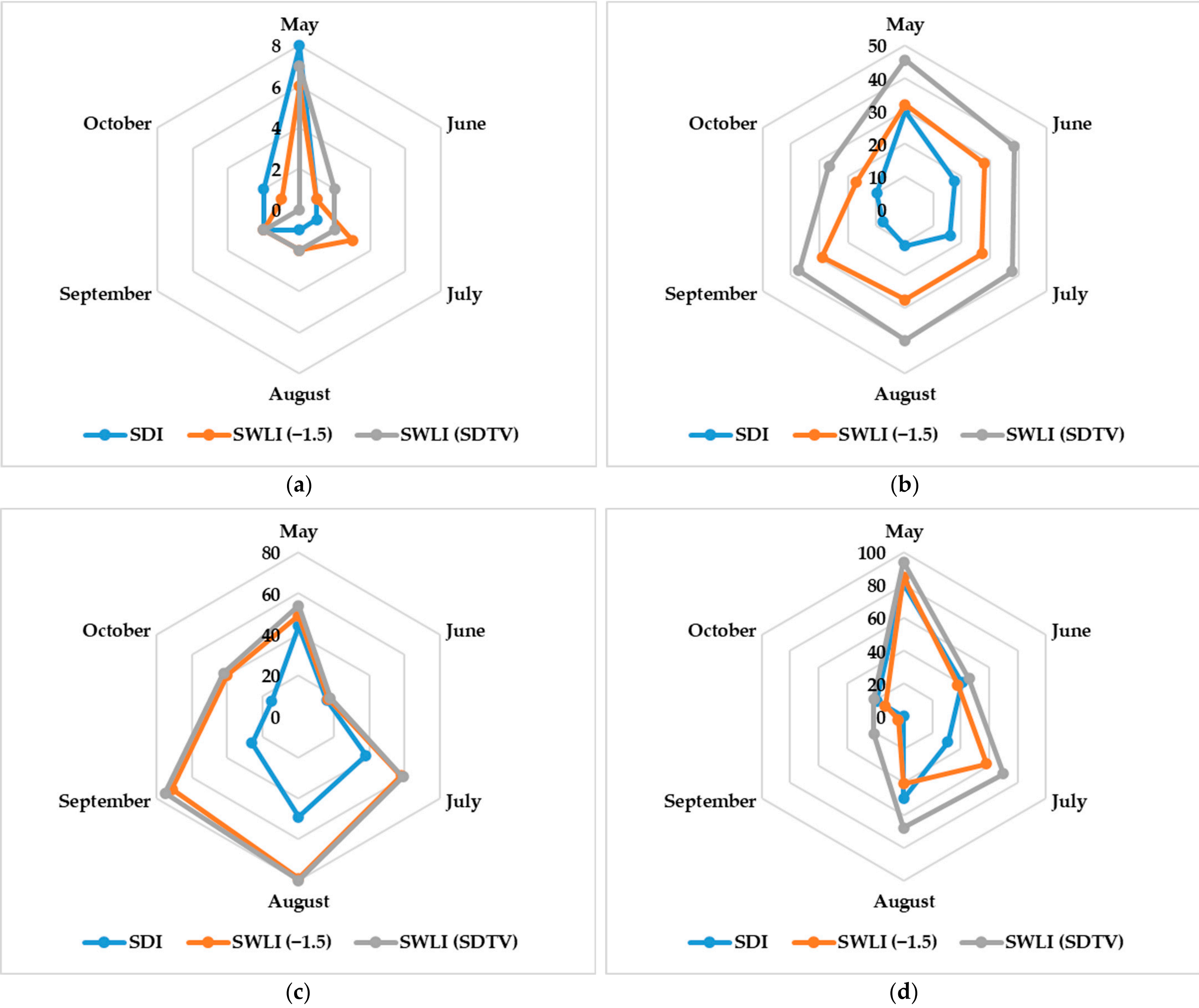
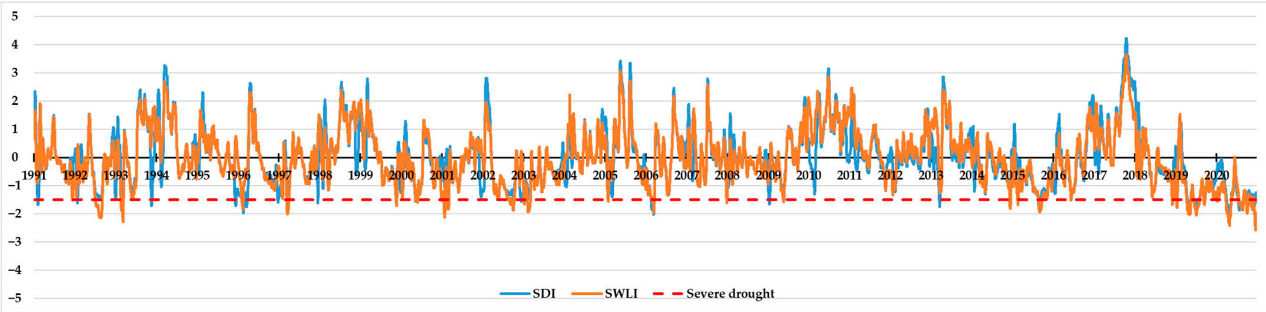


Figure 3. Comparison between SWLI and SDI: (**a**) the number of rivers with the driest months (the largest number of severely dry days); (**b**) average number of severely dry days by month (during 1991–2020) for rivers within Lithuania; (**c**) Nemunas-Smalininkai; (**d**) Žeimena-Pabradė.

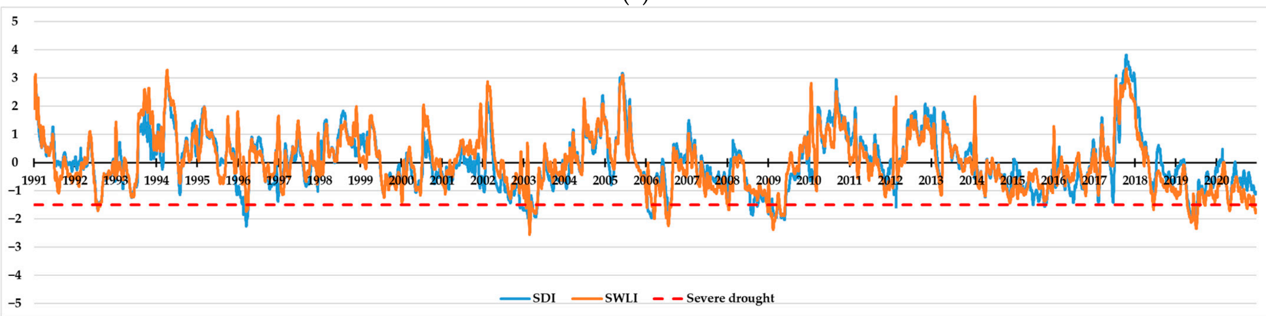
3.2. Analysis of Hydrological Drought in Lithuania Using SWLI

As mentioned above, 15 representative rivers were analyzed using the SWLI index. Fluctuations of the SWLI and SDI indices are presented in Figure 4. Several severe droughts were observed in most rivers: the first quarter of 1996 (corresponds to the cold period), the first quarter of 2003 (corresponds to the cold period), the end of 2005 and most of 2006, and short-term periods of severe drought during 2013–2016. Additionally, from mid-2018, the SWLI index had practically no positive values. The prolonged wet period with maximum values from the middle of 2017 (lasting from 6 to 12 months), which preceded the drought in 2018–2020, should also be noted.

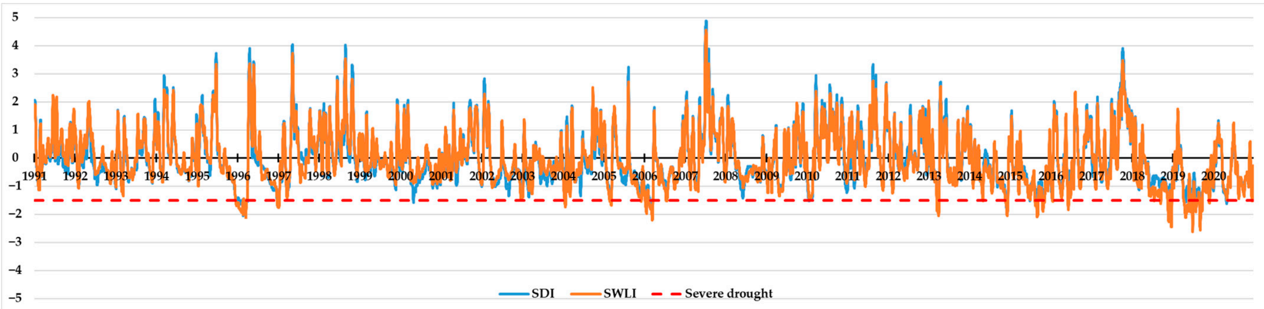
The number of days with a drought index lower than −1.5 (in the warm period) was estimated for each river (Figure 5). During the observed 30 years, drought was most widespread in 2006, 2019 and 2020, but the driest period occurred in 2019. Local, prolonged phenomena of severe drought were also found in 1992 and 2002. It should be emphasized that a general trend of an increase in severely dry days was observed.



(**a**)



(**b**)



(**c**)

Figure 4. Comparison between SWLI and SDI over 30 years: (**a**) Nemunas-Smalininkai; (**b**) Žeimena-Pabradė; (**c**) Šešuvis-Skirgailai.

Year:	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	SUM
Nem-Sma	0	65	0	0	0	0	0	0	0	6	0	41	0	0	0	0	0	0	4	0	0	0	0	0	35	2	0	0	92	83	328
Mer-Puv	0	4	0	0	0	0	0	0	19	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	24	8	0	0	83	161	304
Ner-Jon	0	61	33	0	0	7	10	0	6	15	0	40	4	0	0	0	0	0	37	0	0	0	0	0	13	0	0	0	82	17	325
Zei-Pab	0	48	0	0	0	0	0	0	0	0	0	0	16	0	0	57	0	0	42	0	0	0	0	0	3	0	0	14	100	40	320
Sve-Ukm	54	134	59	13	0	0	0	0	3	8	0	0	3	0	0	49	9	4	35	0	0	0	0	2	0	0	0	0	6	14	393
Nev-Pan	0	0	0	0	0	0	0	0	0	6	0	25	30	10	10	112	0	0	0	0	0	0	0	0	1	11	0	36	131	59	431
Dub-Lyd	0	2	30	0	0	0	0	0	0	3	0	0	0	0	0	24	0	4	0	0	0	0	0	0	0	0	0	0	16	9	88
Mit-Zin	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	15	0	5	0	0	0	0	0	6	0	0	0	14	7	17	72
Ses-Ski	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	5	48	9	0	14	114	8	210
Min-Kar	0	0	3	10	0	0	0	0	0	5	0	13	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	9	0	51
Svy-Gun	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3
Nem-Tab	0	8	35	0	0	11	0	0	1	21	0	48	0	2	0	28	0	0	0	0	0	0	0	0	0	0	0	0	13	4	171
Mus-Ust	0	30	5	0	0	0	0	0	68	0	0	126	12	0	0	30	0	15	0	0	0	0	0	0	17	0	0	0	16	5	324
Ven-Lec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39	0	0	0	0	0	0	0	0	24	4	0	34	57	60	218
Bar-Sku	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	3	10	0	0	0	17	15	0	0	5	24	52	142

Figure 5. Temporal distribution of hydrological droughts according to SDTV. For each river the number of dry days were represented by color scale, where green—year without dry days and red—the highest number of dry days per year.

Certain patterns can be distinguished if we consider the spatial distribution of droughts (Figure 6). From 1991 to 1995, the highest number of severe and extreme hydrological droughts was concentrated in the southeastern hydrological region. Between 2001 and 2010, most droughts occurred in the central hydrological region. In recent years, drought has covered the entire territory of Lithuania.

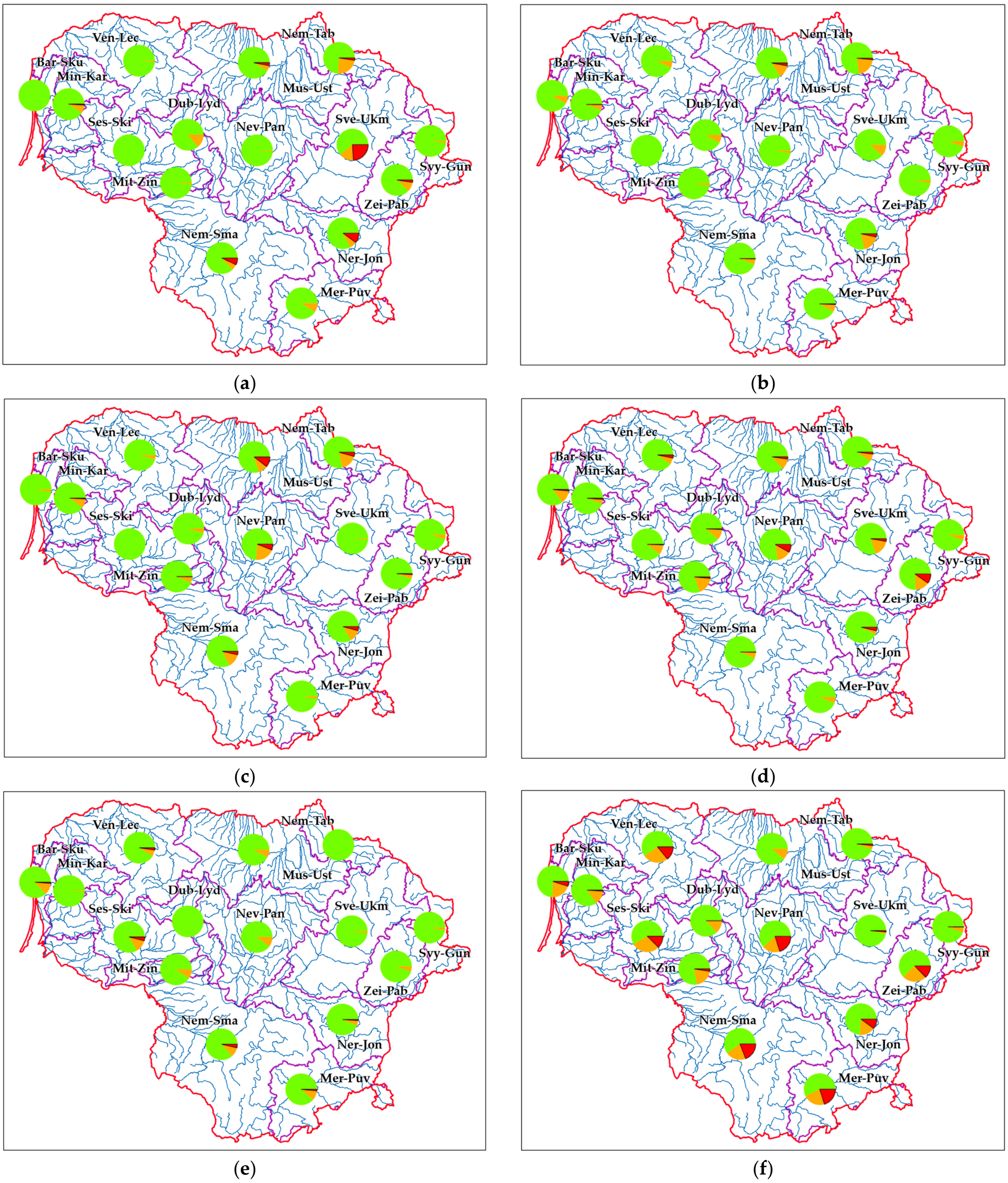


Figure 6. Spatial and temporal distribution of hydrological droughts (in %) for six historical periods: (**a**) 1991–1995; (**b**) 1996–2000; (**c**) 2001–2005; (**d**) 2006–2010; (**e**) 2011–2015; (**f**) 2016–2020. On the circular diagrams, conditions close to normal are shown in green, the average drought in orange, severe and extreme droughts in red.

Table 6 shows the maximum duration of drought with SWLI values below −1.5. Overall, the prolonged droughts were consistent with the driest years identified above. According to this table, rivers in the southeastern and central hydrological regions tended to experience the most prolonged droughts at the end of the study period. On the contrary, they were present in the rivers of the central hydrological region in the middle of the study period.

Table 6. Maximum drought duration in days according to threshold −1.5 and SDTV.

№	WGS	The Longest Drought at Warm Period (SDTV)	Year	The Longest Drought at Warm Period (−1.5)	Year
1	Nem-Sma	65	1992	64	1992
2	Mer-Puv	48	2020	46	2020
3	Ner-Jon	82	2019	81	2019
4	Zei-Pab	57	2006	43	2006/2019
5	Sve-Ukm	134	1992	119	1992
6	Nev-Pan	58	2019	37	2006
7	Dub-Lyd	30	1993	7	2006
8	Mit-Zin	12	2020	11	2020
9	Ses-Ski	34	2019	29	2019
10	Min-Kar	11	2006	10	2006
11	Svy-Gun	3	2020	2	2020
12	Nem-Tab	32	2002	28	2002
13	Mus-Ust	76	2002	44	2002
14	Ven-Lec	44	2019	43	2019
15	Bar-Sku	23	2020	17	2019

3.3. Projections of Hydrological Droughts Using SWLI

Analysis of the hydrological drought in the future (Appendix A and Table 7) reveals that most droughts are expected in the distant future. The only exception is the behavior of the Šešuvis River in the RCP4.5 scenario. This may be caused by a stronger dependence on precipitation, while the Nemunas and Žeimena have a dominant underground feeding source.

Table 7. Days with severe drought (based on SWLI) in the near and distant future.

	Nem-Sma		Zei-Pab		Ses-Ski	
	RCP4.5	**RCP8.5**	**RCP4.5**	**RCP8.5**	**RCP4.5**	**RCP8.5**
Near Future	219	25	269	293	375	214
Far Future	433	701	785	761	371	482

A comparison of the projected and historical data (Table 8) revealed an increase in the percentage of severe and extreme drought in the future in rivers such as the Žeimena and Šešuvis. However, for the Nemunas River, the opposite tendency was observed. Such a difference may be due to the larger catchment area and a decrease in the range of water level fluctuations.

Table 8. Droughts percentages in past and future scenarios.

		Nem-Sma	Zei-Pab	Ses-Ski
Historical	1991–2020	5.94	5.80	3.80
RCP 4.5	2021–2060	2.98	3.65	5.10
	2061–2100	5.88	10.67	5.04
RCP 8.5	2021–2060	0.34	3.98	2.91
	2061–2100	9.52	10.34	6.55

According to Table 9 and Figure 7, it can be concluded that the appearance of more extreme hydrological droughts is expected in the future, especially in the period 2061–2100. Under scenario RCP4.5, all three rivers showed a slight negative decreasing trend in the long term. For scenario 8.5, we can observe more significant negative changes for the Nemunas and Žeimena rivers, but, at the same time, significant positive changes for the Šešuvis.

Table 9. Minimum values of SWLI index in the past and future.

	Observation (1986–2005)	RCP4.5 NF	RCP4.5 FF	RCP8.5 NF	RCP8.5 FF
Nem-Sma	−2.42	−1.96	−3.04	−1.71	−2.67
Zei-Pab	−2.35	−1.95	−2.79	−2.43	−2.48
Ses-Ski	−2.63	−3.01	−3.33	−2.59	−3.25

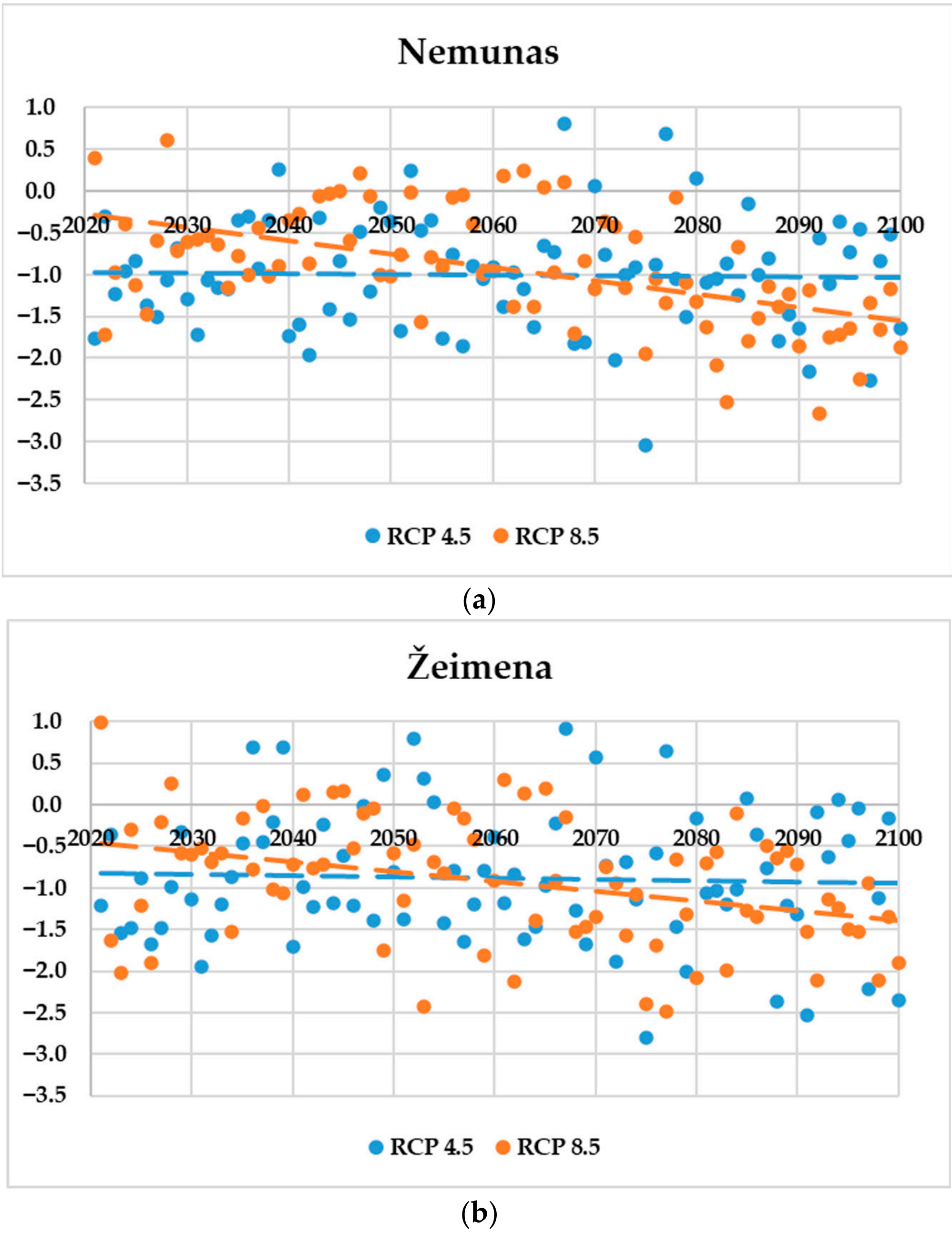
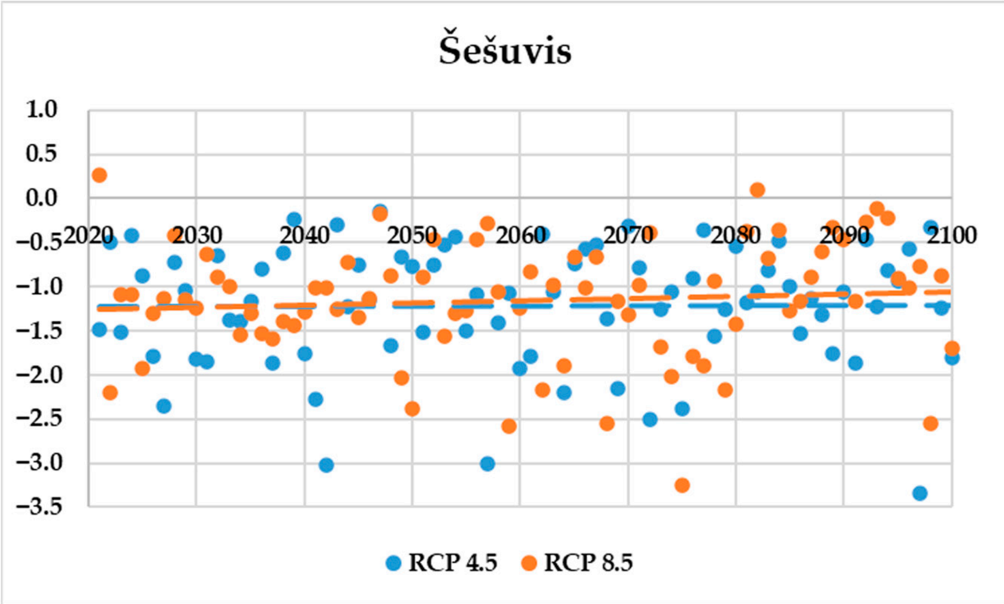


Figure 7. *Cont.*

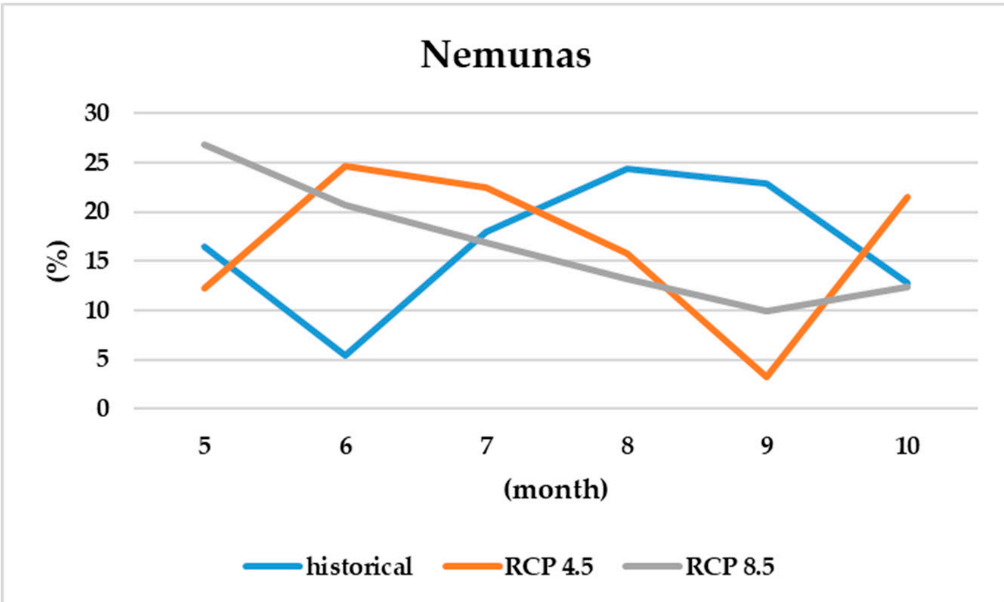


(**c**)

Figure 7. Minimum values of the warm period according to modeled data during the period of 2021–2100 (SWLI index): (**a**) Nemunas-Smalininkai; (**b**) Žeimena-Pabradė; (**c**) Šešuvis-Skirgailai. The dotted lines represent the trend lines for each RCP scenario according to color.

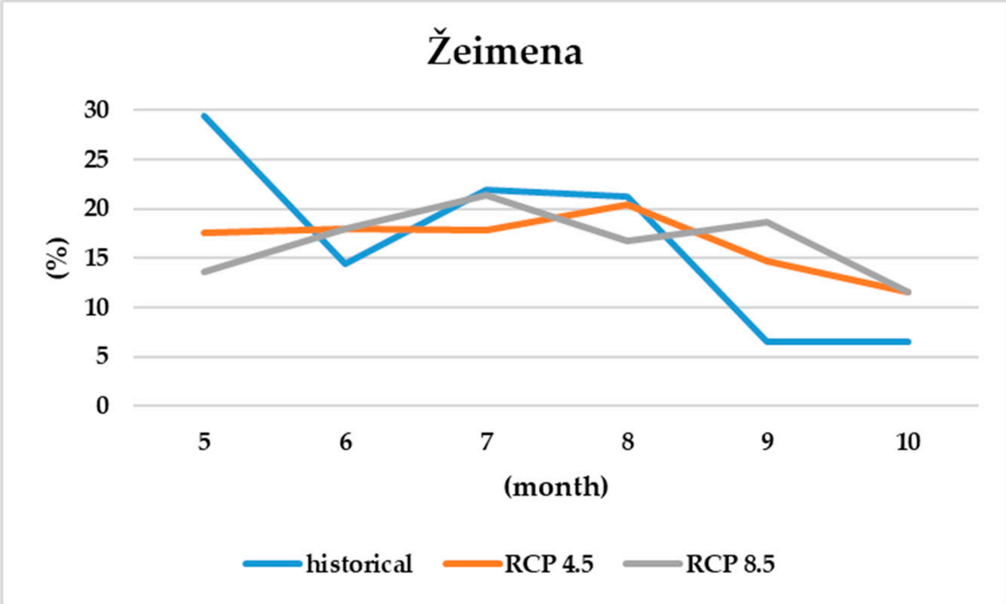
The models predict the formation of a wet period for the Nemunas and Žeimena rivers in the period 2040–2070 (Figure 7).

The distribution of severe and extreme droughts during the warm period was also investigated (Figure 8). When comparing the projection data with the historical period, changes were observed in all three basins, but no clear trends were identified. This type of change can be related to feeding sources and climate change.

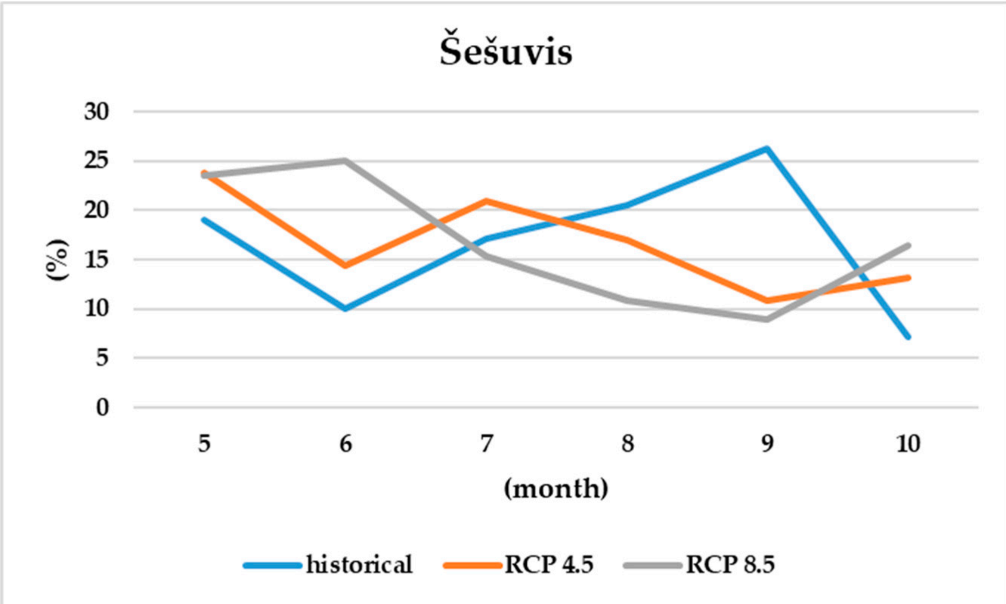


(**a**)

Figure 8. *Cont.*



(**b**)



(**c**)

Figure 8. Percentage of droughts (according to SDTV) by month: (**a**) Nemunas-Smalininkai; (**b**) Žeimena-Pabradė; (**c**) Šešuvis-Skirgailai.

4. Discussion and Conclusions

The present study was designed to determine the suitability of the standardized water level index (SWLI) to monitor, follow and forecast hydrological drought conditions in Lithuania.

The hydrological drought index SDI, in turn, was developed [25] based on the concept of the widely known and recognized standardized precipitation index (SPI) [17,24]. A number of other hydrological indices are calculated similarly to SPI (e.g., standardized reservoir supply index (SRSI), standardized streamflow index (SSFI), standardized water-level index (SWI)) [15].

The developed methodology was adapted to analyze hydrological droughts in Lithuanian river catchments over the past three decades. The hydrological identification and quantification of droughts using the modified SWLI have led to the discovery of past and future trends.

The results indicated the most severe droughts over the 30 years in 1992, 2002, 2006, 2019 and 2020. Droughts in Lithuania in 1992, 2002 and 2006 were identified using other methodologies [19,37]. The vegetation seasons of 1992 and 2002 were also described as extremely dry in the eastern Baltic Sea region [38]. The highest rates of flow intermittence in 1992, 2002, 2006 and 2018 were established by Šarauskienė et al. [30]. According to agricultural drought criteria, from 1992 to 2006, as well as in 2018 and 2019, large areas of Lithuania suffered from extreme dryness [39]. According to [40], over the studied period of 1950–2012, the longest and most severe and widespread drought event in the Baltic States was recorded during 2005–2009; in Eastern Europe, the most prolonged was in 1992–1995 and the most severe in 1989–1991. The year 2019 was the warmest year on record in Poland [41]. Blauhut et al. [42] listed the Lithuanian neighbors—Belarus, Latvia and Poland—as particularly affected by the multi-year drought of 2018–2019. Furthermore, the 2018–2020 drought event of extraordinary intensity covered a significant part of Europe [43]. Moreover, it was followed by a drought in 2022 that was considered the worst in at least 500 years [44].

In general, using the developed methodology, a positive trend in the number of severely dry days was detected over the last three decades. A similar pattern of results was obtained in the neighboring northern part of Poland: based on different indices, river flow decrease was identified for the period of 1981–2016 [45]. These basic findings are consistent with research [46] showing the ongoing negative water balance of the Greater Poland region in the years following 1988. In Latvia, since the early 1990s, remarkably drier conditions have been observed more often as well [47]. Our findings are consistent with what was found in the study [48], which analyzed long-term changes in drought indices of central and eastern European countries during 1949–2018. These authors estimated drying trends in the north, the Baltic countries and northern Belarus.

In individual rivers, the maximum duration of severe droughts lasted from 3 to 161 days. According to SWLI, in 1992, hydrological drought covered eight sub-basins (out of 15) and had the maximum duration from 2 to 134 days in 2006–2012 and 5–112 days in 2019–2020—14 rivers in each year—with a maximum duration of 131 days in 2019 (Nevėžis River) and 161 days in 2020 (Merkys River). According to SWLI, in 1992, hydrological drought covered 8 sub-basins (out of 15) and had the maximum duration from 2 to 134 days; 2006–2012, with 5–112 days; and in 2019–2020 period—14 rivers in each year, with maximum duration 131 days in 2019 (Nevėžis River) and 161 days in 2020 (Merkys River). At the beginning of the study period, hydrological drought events were identified in the southeastern catchments, while, in the first decade of this century, they were indicated in the rivers of the central part of Lithuania. However, more recently (2016–2020), drought events were detected in each analyzed river catchment. The most prone to the hydrological drought was the Nevėžis river, where the percentage of severe droughts in the warm period was 7.81% (when, on average in Lithuania, it is 4.08%). These findings agree with a previous study [31], which, based on three different drought indices, revealed different patterns of drought in the hydrological regions of Lithuania.

As was already mentioned, the lowest amount of drought events were detected in the Svyla river. Since it is considered intermittent [30], we expected that this small river would distinguish itself by the most prolonged drought. A possible explanation for this case might be that our study applied the drought index based on river water levels. We suppose that during the period of low flow (which almost coincides with the warm period), the vegetation of the channel might have changed the hydrodynamics, i.e., the river stopped flowing. However, some water (the level of which can be measured) was still available in the river channel (the complex influence of aquatic macrophytes in regulating flow rates and water levels is discussed by [49]). Therefore, the case of this intermittent river shows some limitations of the SWLI methodology.

The developed methodology was applied to forecasting hydrological drought. In general, the obtained results demonstrated that the selected river catchments would likely suffer from more extreme hydrological droughts, especially under RCP8.5 at the end of the century. At the same time, it is evident that, in climate change conditions, the behavior of river catchments with different physical-geographical features is complex and challenging to predict. These findings support the arguments that the results of drought projections highly depend on the regions and drought indices considered [50,51].

It should be emphasized that the results obtained using the widely recognized stream drought index (SDI) developed by Nalbantis and Tsakiris [25] with the standardized water level index (SWLI) proposed by Kugytė and Valiuškevičius [28] are rather similar. SWLI can, therefore, be used as an operational index for hydrological drought monitoring and severe drought detection. It covers the essential criteria of a (hydrological) drought index [15,52,53] as it is simple (can be understood by non-experts), easily calculated, based on available real-time data, has a physical meaning, is sensitive to various drought conditions and can be used for forecasting.

Author Contributions: Conceptualization, S.N. and J.K.; methodology, S.N., D.Š. and A.P.; software, S.N.; modeling, S.N.; formal analysis, D.Š. and A.P.; investigation, J.K.; data curation, S.N.; writing—original draft preparation, S.N. and D.Š.; writing—review and editing, J.K. and A.P.; visualization, S.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Acknowledgments: The authors wish to thank the Lithuanian Hydrometeorological Service for providing the daily water level and discharge data.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

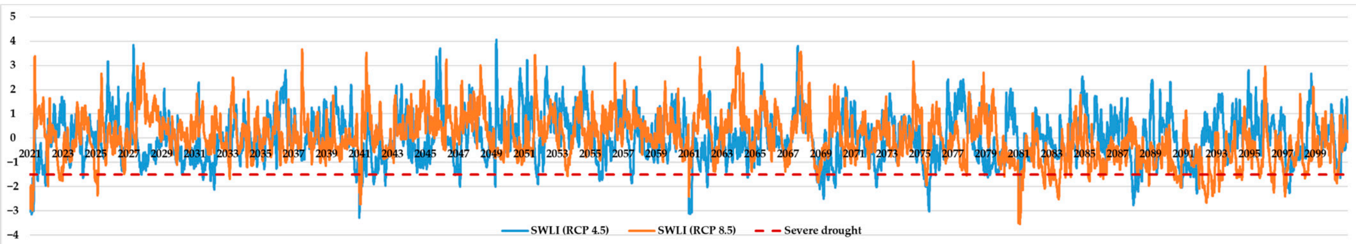


Figure A1. Comparison SWLI at RCP 4.5 and SWLI at RCP 8.5, the Nemunas river.

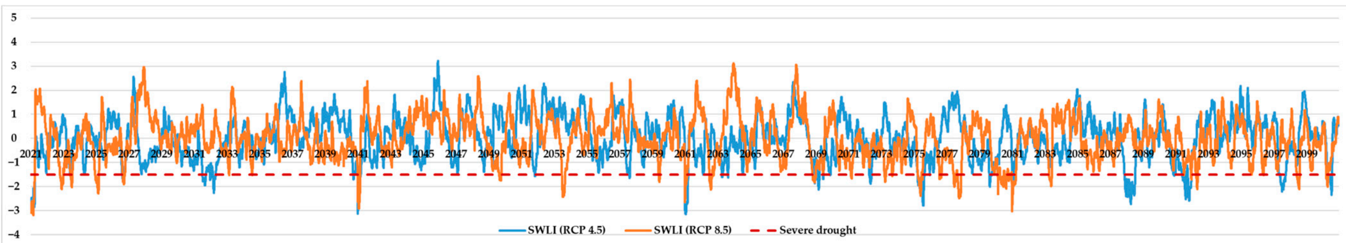


Figure A2. Comparison SWLI at RCP 4.5 and SWLI at RCP 8.5, the Žeimena river.

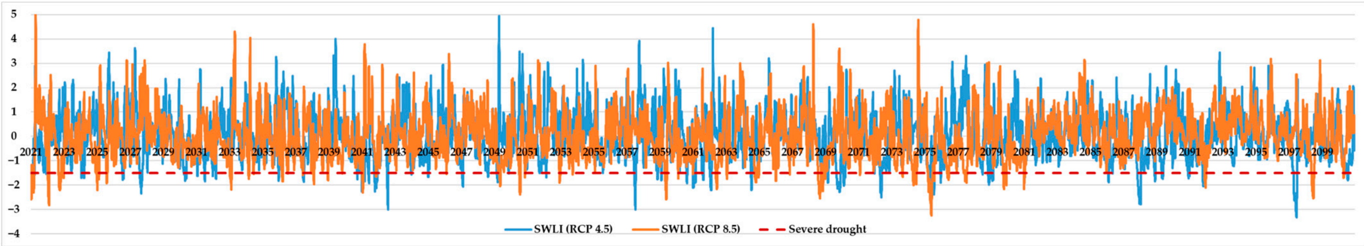


Figure A3. Comparison SWLI at RCP 4.5 and SWLI at RCP 8.5, the Šešuvis river.

References

1. European Environment Agency. *Economic Losses from Weather and Climate-Related Extremes in Europe Reached around Half a Trillion Euros over Past 40 Years*; European Environment Agency: Copenhagen, Denmark, 2021; p. 21. [CrossRef]
2. Dai, A. Drought under global warming: A review. *Wiley Interdiscip. Rev. Clim. Chang.* **2011**, *2*, 45–65. [CrossRef]
3. Asadieh, B.; Krakauer, N.Y. Global change in streamflow extremes under climate change over the 21st century. *Hydrol. Earth Syst. Sci.* **2017**, *21*, 5863–5874. [CrossRef]
4. Intergovernmental Panel on Climate Change (IPCC). Summary for Policymakers. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L.M.I., Huang, M., et al., Eds.; Cambridge University Press: Cambridge, UK, 2021.
5. Wilhite, D.A.; Glantz, M.H. Understanding: The Drought Phenomenon: The Role of Definitions. *Water Int.* **1985**, *10*, 111–120. [CrossRef]
6. Van Loon, A. Hydrological drought explained. *WIREs Water* **2015**, *2*, 359–392. [CrossRef]
7. Stahl, K.; Vidal, J.-P.; Hannaford, J.; Tijdeman, E.; Laaha, G.; Gauster, T.; Tallaksen, L.M.; Stahl, K.; Vidal, J.-P.; Hannaford, J.; et al. The Challenges of Hydrological Drought Definition, Quantification and Communication: An Interdisciplinary Perspective. *PIAHS* **2020**, *383*, 291–295. [CrossRef]
8. Global Water Partnership Central and Eastern Europe. *Guidelines for the Preparation of Drought Management Plans*; Development and Implementation in the Context of the EU Water Framework Directive; Global Water Partnership Central and Eastern Europe: Bratislava, Slovakia, 2015. Available online: https://climate-adapt.eea.europa.eu/en/metadata/guidances/guidelines-for-preparation-of-the-drought-management-plans-1/guidelines-preparation-drought (accessed on 23 December 2022).
9. Barker, L.J.; Hannaford, J.; Chiverton, A.; Svensson, C.; Barker, L.J.; Hannaford, J.; Chiverton, A.; Svensson, C. From Meteorological to Hydrological Drought Using Standardised Indicators. *Hydrol. Earth Syst. Sci.* **2015**, *12*, 12827–12875. [CrossRef]
10. Haslinger, K.; Koffler, D.; Schöner, W.; Laaha, G. Exploring the Link between Meteorological Drought and Streamflow: Effects of Climate-Catchment Interaction. *Water Resour. Res.* **2014**, *50*, 2468–2487. [CrossRef]
11. Stoelzle, M.; Stahl, K.; Morhard, A.; Weiler, M. Streamflow Sensitivity to Drought Scenarios in Catchments with Different Geology. *Geophys. Res. Lett.* **2014**, *41*, 6174–6183. [CrossRef]
12. Rossi, G. Drought Mitigation Measures: A Comprehensive Framework. In *Drought and Drought Mitigation in Europe*; Advances in Natural and Technological Hazards Research; Vogt, J.V., Somma, F., Eds.; Springer: Dordrecht, The Netherlands, 2000; pp. 233–246.
13. Kundzewicz, Z.W. Adaptation to Floods and Droughts in the Baltic Sea Basin under Climate Change. *Boreal Environ. Res.* **2009**, *14*, 193–203.
14. Solh, M.; Van Ginkel, M. Drought Preparedness and Drought Mitigation in the Developing World's Drylands. *Weather Clim. Extrem.* **2014**, *3*, 62–66. [CrossRef]
15. World Meteorological Organization (WMO); Global Water Partnership (GWP). *Handbook of Drought Indicators and Indices*; WMO: Geneva, Switzerland; GWP: Geneva, Switzerland, 2016; pp. 1–52.
16. Yihdego, Y.; Vaheddoost, B.; Al-Weshah, R.A. Drought indices and indicators revisited. *Arab. J. Geosci.* **2019**, *12*, 69. [CrossRef]
17. Hayes, M.J.; Svoboda, M.; Wall, N.A.; Widhalm, M. The Lincoln Declaration on Drought Indices: Universal Meteorological Drought Index Recommended. *Bull. Am. Meteorol. Soc.* **2011**, *92*, 485–488. [CrossRef]
18. Rimkus, E.; Valiukas, D.; Kažys, J.; Gečaitė, I.; Stonevičius, E. Dryness dynamics of the Baltic Sea region. *Baltica* **2012**, *25*, 129–142. [CrossRef]
19. Rimkus, E.; Stonevičius, E.; Korneev, V.; Kažys, J.; Valiuškevičius, G.; Pakhomau, A. Dynamics of meteorological and hydrological droughts in the Neman river basin. *Environ. Res. Lett.* **2013**, *8*, 045014. [CrossRef]
20. Stonevičius, E.; Rimkus, E.; Kažys, J.; Bukantis, A.; Kriaučiūniene, J.; Akstinas, V.; Jakimavičius, D.; Povilaitis, A.; Ložys, L.; Kesminas, V.; et al. Recent Aridity Trends and Future Projections in the Nemunas River Basin. *Clim. Res.* **2018**, *75*, 143–154. [CrossRef]
21. Šarauskienė, D.; Akstinas, V.; Kriaučiūnienė, J.; Jakimavičius, D.; Bukantis, A.; Kažys, J.; Povilaitis, A.; Ložys, L.; Kesminas, V.; Virbickas, T.; et al. Projection of Lithuanian river runoff, temperature and their extremes under climate change. *Hydrol. Res.* **2018**, *49*, 344–362. [CrossRef]

22. Byun, H.R.; Wilhite, D.A. Objective Quantification of Drought Severity and Duration. *J. Clim.* **1999**, *12*, 2747–2756. [CrossRef]
23. Stonevičius, E.; Stankūnavičius, G.; Jalinskas, P. The Warm Season Runoff Dependence on the Drought Index in Lithuania. In Proceedings of the International Conference BALWOIS 2006, Ohrid, North Macedonia, 23–26 May 2006.
24. McKee, T.B.; Doesken, N.J.; Kleist, J. The Relationship of Drought Frequency and Duration to Time Scales. In Proceedings of the 8th Conference on Applied Climatology, Anaheim, CA, USA, 17–22 January 1993; pp. 179–184.
25. Nalbantis, I.; Tsakiris, G. Assessment of hydrological drought revisited. *Water Resour. Manag.* **2009**, *23*, 881–897. [CrossRef]
26. Shukla, S.; Wood, A.W. Use of a Standardized Runoff Index for Characterizing Hydrologic Drought. *Geophys. Res. Lett.* **2008**, *35*. [CrossRef]
27. Valiukas, D. Sausrų ir sausų laikotarpių Lietuvoje analizė. Daktaro disertacija. Ph.D. Thesis, Vilniaus Universitetas, Vilnius, Lithuania, 2015.
28. Kugytė, G.; Valiuškevičius, G. Identification of Hydrological Droughts in Lithuanian Rivers. *Geogr. Ir Edukac.* **2021**, *9*, 87–99. [CrossRef]
29. Gailiušis, B.; Jablonskis, J.; Kovalenkovienė, M. Lithuanian Rivers: Hydrography and Runoff. In *Lithuanian Rivers: Hydrography and Runoff*; Lithuanian Energy Institute: Kaunas, Lithuanian, 2001; p. 792.
30. Šarauskienė, D.; Akstinas, V.; Nazarenko, S.; Kriaučiūnienė, J.; Jurgelėnaitė, A. Impact of physico-geographical factors and climate variability on flow intermittency in the rivers of water surplus zone. *Hydrol. Process.* **2020**, *34*, 4727–4739. [CrossRef]
31. Nazarenko, S.; Kriaučiūnienė, J.; Šarauskienė, D.; Jakimavičius, D. Patterns of Past and Future Droughts in Permanent Lowland Rivers. *Water* **2022**, *14*, 71. [CrossRef]
32. Gudmundsson, L.; Bremnes, J.B.; Haugen, J.E.; Engen–Skaugen, T. Technical Note: Downscaling RCM precipitation to the station scale using statistical transformations—A comparison of methods. *Hydrol. Earth Syst. Sci.* **2012**, *16*, 3383–3390. [CrossRef]
33. Sunyer, M.A.; Hundecha, Y.; Lawrence, D.; Madsen, H.; Willems, P.; Martinkova, M.; Vormoor, K.; Bürger, G.; Hanel, M.; Kriaučiūnienė, J.; et al. Inter–comparison of statistical downscaling methods for projection of extreme precipitation in Europe. *Hydrol. Earth Syst. Sci.* **2015**, *19*, 1827–1847. [CrossRef]
34. Bergstrom, S. The HBV model. In *Computer Models of Watershed Hydrology*; Singh, V.P., Ed.; Water Resources Publications: Highlands Ranch, CO, USA, 1995; pp. 443–476.
35. SMHI. *Integrated Hydrological Modelling System, Manual*; Version 5.8; Swedish Meteorological and Hydrological Institute: Norrköping, Sweden, 2005; p. 115.
36. AgriMetSoft. Online Calculators. Available online: https://agrimetsoft.com/calculators/Nash%20Sutcliffe%20model%20Efficiency%20coefficient (accessed on 23 December 2022).
37. Valiukas, D. Droughts analysis in Lithuania using SPI and HTC indices. In Proceedings of the International Conference BALWOIS 2012, Ohrid, North Macedonia, 28 May–2 June 2012; pp. 1–9.
38. Rimkus, E.; Stonevicius, E.; Kilpys, J.; Maciulyte, V.; Valiukas, D. Drought identification in the eastern Baltic region using NDVI. *Earth Syst. Dyn.* **2017**, *8*, 627–637. [CrossRef]
39. Rimkus, E.; Mačiulytė, V.; Stonevičius, E.; Valiukas, D. A revised agricultural drought index in Lithuania. *Agric. Food Sci.* **2020**, *29*, 359–371. [CrossRef]
40. Spinoni, J.; Naumann, G.; Vogt, J.; Barbosa, P. European Drought Climatologies and Trends Based on a Multi-Indicator Approach. *Glob. Planet. Chang.* **2015**, *127*, 50–57. [CrossRef]
41. Ziernicka-Wojtaszek, A. Summer Drought in 2019 on Polish Territory—A Case Study. *Atmosphere* **2021**, *12*, 1475. [CrossRef]
42. Blauhut, V.; Stoelzle, M.; Ahopelto, L.; Brunner, M.I.; Teutschbein, C.; Wendt, D.E.; Akstinas, V.; Bakke, S.J.; Barker, L.J.; Bartošová, L.; et al. Lessons from the 2018-2019 European Droughts: A Collective Need for Unifying Drought Risk Management. *Nat. Hazards Earth Syst. Sci.* **2022**, *22*, 2201–2217. [CrossRef]
43. Rakovec, O.; Samaniego, L.; Hari, V.; Markonis, Y.; Moravec, V.; Thober, S.; Hanel, M.; Kumar, R. The 2018–2020 Multi-Year Drought Sets a New Benchmark in Europe. *Earth's Future* **2022**, *10*, e2021EF002394. [CrossRef]
44. Toreti, A.; Bavera, D.; Acosta Navarro, J.; Cammalleri, C.; de Jager, A.; Di Ciollo, C.; Hrast Essenfelder, A.; Maetens, W.; Magni, D.; Masante, D.; et al. *Drought in Europe August 2022*; Publications Office of the European Union: Luxembourg, 2022; JRC130493. [CrossRef]
45. Piniewski, M.; Marcinkowski, P.; Kundzewicz, Z.W. Trend detection in river flow indices in Poland. *Acta Geophys.* **2018**, *66*, 347–360. [CrossRef]
46. Marsz, A.A.; Sobkowiak, L.; Styszyńska, A.; Wrzesiński, D. Causes and Course of Climate Change and Its Hydrological Consequences in the Greater Poland Region in 1951–2020. *Quaest. Geogr.* **2022**, *41*, 183–206. [CrossRef]
47. Briede, A.; Lizuma, L. Analysis of High Temperature Extremes and Climatological Drought Long-Term Tendencies in Latvia. In Proceedings of the 10th European Conference on Applications of Meteorology (ECAM), Zürich, Switzerland, 13–17 September 2010.
48. Jaagus, J.; Aasa, A.; Aniskevich, S.; Boincean, B.; Bojariu, R.; Briede, A.; Danilovich, I.; Castro, F.D.; Dumitrescu, A.; Labuda, M.; et al. Long-Term Changes in Drought Indices in Eastern and Central Europe. *Int. J. Clim.* **2022**, *42*, 225–249. [CrossRef]
49. Cornacchia, L.; Wharton, G.; Davies, G.; Grabowski, R.C.; Temmerman, S.; Van Der Wal, D.; Bouma, T.J.; Van De Koppel, J. Self-Organization of River Vegetation Leads to Emergent Buffering of River Flows and Water Levels. *Proc. R. Soc. B* **2020**, *287*, 20201147. [CrossRef] [PubMed]
50. Sutanto, S.J.; Van Lanen, H.A.J. Streamflow Drought: Implication of Drought Definitions and Its Application for Drought Forecasting. *Hydrol. Earth Syst. Sci.* **2021**, *25*, 3991–4023. [CrossRef]

51. Zeng, J.; Li, J.; Lu, X.; Wei, Z.; Shangguan, W.; Zhang, S.; Dai, Y.; Zhang, S. Assessment of Global Meteorological, Hydrological and Agricultural Drought under Future Warming Based on CMIP6. *Atmos. Ocean. Sci. Lett.* **2022**, *15*, 100143. [CrossRef]
52. Gosling, R.D.; Zaidman, M.; Wann, M.; Rodgers, P.J. *How Low Can You Go? Using Drought Indices to Protect Environmental Flows in Scottish Rivers*; SEPA: Gulf Breeze, FL, USA, 2012; pp. 1–6. [CrossRef]
53. Drought Management Guidelines. Available online: https://projects.iamz.ciheam.org/medroplan/guidelines/archivos/guidelines_english.pdf (accessed on 20 January 2023).