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ANALYSIS OF DROUGHTS AND DRY PERIODS IN LITHUANIA

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INTRODUCTION

Droughts are one of the most dangerous and damage-causing natural phenomena. Droughts may form at any season of the year, both in the areas of excessive moisture, and in the territories with moisture deficit (Khadar et al., 2009). Droughts and their consequences cause substantial damages and losses to the sectors of agriculture, energy, nature, they have significant social and other impacts (Wilhite et al., 2000).

On the basis of physical geographic conditions, Lithuania belongs to the excess moisture zone, i.e. the annual amount of precipitation exceeds the evaporation, and for this reason droughts are not considered to be frequent phenomena in Lithuania. However, due to climate change, with increase of average air temperature, increase of transpiration and evapotranspiration, and with the same amount of precipitation during a shorter period (more frequent heavy precipitation events), the conditions for the formation of short-term droughts during the warm period of the year became more favourable.

A drought differs from other meteorological phenomena because it is not very easy to define the beginning of a drought and its duration as the impact of the meteorological phenomena is summarized for longer periods. One important peculiarity of droughts is that it is impossible to measure them in direct way, i.e. they are usually identified on the basis of the so-called “drought index”. Four types of droughts are usually distinguished worldwide: meteorological, agrometeorological, hydrological, and socioeconomic droughts.

Research object

Droughts and dry periods in Lithuanian and the Baltic Sea region.

The aim of the study

The analysis of droughts and dry periods and their dynamics according to various drought indices.

Research tasks

1. To review the definitions of meteorological, agrometeorological, hydrological and socioeconomic droughts and its development, worldwide and in Lithuania.

2. To carry out the comparative analysis of indices used to identify various types of droughts.

3. To use SPI (Standardized Precipitation Index) for the analysis of meteorological droughts dynamics in Lithuania for 1961–2010, in the Baltic Sea region for 1960–2009 as well as in Vilnius for 1891–2010.

4. To make meteorological droughts predictions for the 21st century for Lithuania and the Baltic Sea region according to SPI.

5. To analyse the droughts in Lithuania between 1961 and 2010 according to HTC and to evaluate the advantages and disadvantages of this index.

6. To investigate the opportunity of the use of data about the soil moisture for the identification of agrometeorogical droughts in Lithuania.

7. According to SRI, to analyse the frequency of droughts between 1961-2010 in Lithuania, and to evaluate its suitability for the identification of the hydrological droughts in Lithuania.

8. To evaluate the relationships between the meteorological and hydrological indices used for drought identification.

9. To review the socioeconomic impact of droughts for various areas of the Lithuanian economy.

Propositions to be defended

1. The concept of a drought in different countries of the world is mostly defined by the consequences of the droughts. In Lithuania, droughts are commonly associated with the agrometeorological droughts. The HTC used to identify the droughts in Lithuania does not fully evaluate the beginning of the droughts and their intensity. This index is not suitable for the identification of agrometeorological droughts. For this reason, it is necessary to improve the calculation methods for this index or to use several indices for the identification of the agrometeorological droughts.

2. In Lithuania, and the Baltic Sea region, the total number of the droughts identified using the SPI is decreasing, but the number of short-term meteorological

droughts during the summer period is increasing. It is probable that similar tendencies might remain in the 21st century.

3. The droughts according to HTC during the growing season become more frequent in Lithuania and cover larger territories.

4. The hydrological droughts of various durations according to SRI at the analysed Lithuanian river basins decreased in number. For the identification of the hydrological droughts the best to use SRI1 and SRI2.

Scientific novelty of the study

The number of researches made in Lithuania in the field of droughts is rather small, and almost all of them were made during the last decades. One of the most important reasons for this can be the fact that droughts did not cause significant threats in Lithuania for quite a long period of time and only some more attention to this phenomena was allocated after the extreme droughts in Lithuania during the last decades. Moreover, the droughts in Lithuania are mostly related to the warm period of the year and their damage to the agricultural sector, and a little less to the forestry sector.

Up till now, the main focus in Lithuania was on the agrometeorological droughts with very little attention being paid to meteorological, hydrological, and socioeconomical droughts. This thesis, for the fir st time in Lithuania, analyses all 4 drought types and explains their differences.

The World Meteorological Organization (2009) recommended to all world hydrometeorology services to use the SPI (Standard Precipitation Index) as a universal meteorological drought index. However, for the analysis of droughts in Lithuania, this index has not been yet widely used. This thesis, for the first time in Lithuania, will cover a detailed analysis of droughts made on basis of the SPI index, and will present climatic projections of the droughts freguency for the 21st century in Lithuania and the Baltic Sea region.

In Lithuania, for the identification of droughts, the Hydrothermal coefficient (HTC) of Selianinov is used, which is also approved by formal legal acts. This index was proposed by a Russian scientist G. T. Selyaninov in 1928. This thesis analyses droughts according to HTC, reviews the disadvantages of the application of this index, provides recommendations as how to use and interpret the HTC.

In Lithuania, little attention so far has been paid also to the hydrological droughts; this is why the hydrological droughts analysis according to SRI (Standardized Runoff Index) was made in the basins of several Lithuanian rivers.

The relevance of the study

At present, for identification of droughts the only method is officially used in Lithuania – it is Selianov's hydrothermal coefficient (HTC). However, this method is not suitable for the identification of agrometeorological droughts because it is not related to the soil moisture and consequences caused by droughts. This is why, for the evaluation of the agrometeorological droughts and insurance benefits paid for the consequences and damages, it is necessary to use the information about the moisture of soil from the reconstructed network of the agrometeorological stations. During the evaluation of droughts using this index, there are also lots of interpretation problems; so necessary to provide recommendations on the basis of which to enable all users of this index to interpret the received results in a similar manner.

The World Meteorological Organization recommends to use the SPI for the identification of the meteorological droughts. For this reason, the analysis of its suitability and usage possibilities is needed. By using the SPI, it would be easier to start integration into the joint European droughts monitoring system.

Droughts are dangerous meteorological phenomena able to cause huge damages. The results of this thesis show that despite the humidity of climate in Lithuanian is increasing, the number of short-term summer droughts also increasing. Similar tendencies can be predicted for the 21st century. This is why it is important to identify droughts of various types in a timely manner and to undertake all necessary measures for the minimisation of their impact and/or adaptation to this impact.

The same conclusions are also provided in the report published in 2009 by the European Environment Agency (EEA). In this report it is emphasized that water insufficiently problem becomes more and more important in the Northern European countries. It is possible that due to climate changes, droughts will be more frequent and more intensive in the future, and the problem of water insufficiency will be more serious during the summer months (EEA, 2009). This report also emphasises that it is important both the EU level and the national level, to integrate water policy into other policies and their targets. These targets will have to be implemented by Lithuania, and for this reason the appropriate knowledge about droughts is needed.

Applicability

This thesis can be useful for the educational purposes enabling to widen the knowledge about droughts and their definition, and the damages made by droughts. The results of this thesis can be used in the areas of climatology, hydrology, ecology, agriculture, forestry and etc.

This thesis can also be helpful for the improvement of the scheme related to insurance benefits and compensations for drought damages.

The analysis of meteorological and hydrological droughts and their projections for the 21st century for Lithuania and the Baltic Sea region can be useful for preparation of plans for water and drought management, creation of adaptation to climate change strategies.

After the drought analysis was made using the HTC, recommendations were provided to all users of this index. There is also a new, more specified definition of a drought based on HTC which could be used instead of the existing one.

After the drought analysis was made using SPI, this drought evaluation method can be used as the main or additional/supplementary method for drought identification in Lithuania.

The results of this thesis can also be useful for further researches of similar character.

Approbation of results

The results have been published in 10 scientific papers; four of them in ISI WOS journals. The results also have been presented at 4 international and 3 national scientific conferences (the list of scientific publications and conference presentations is provided in the final section underneath the summary in English).

Structure

The dissertation consists of the following parts: introduction, review of investigation, methodology, research results, conclusions, references and annexes (as recommended by Regulation No. VI-4 of the Research Council of Lithuania of 2003). The work includes 67 figures (diagrams, maps, and schemes), 33 tables, 355 references.

1. CONCEPT OF DROUGHTS − WORLWIDE AND IN LITHUANIA

A drought is a dangerous meteorological phenomenon which is hard to define. The definition of a drought has always been a certain obstacle for drought analysis and monitoring (Dracup et al., 1980). The issue of drought definition and its concept was tried to be solved worldwide for many times (Yevjevich, 1967; Dracup et al., 1980; Wilhite and Glantz, 1987; Pereira, 1990; Rodriguez-Iturbe, 2000; Agnew and Anderson, 1992; Wilhite, 1993) and the most common conclusion was that there is no exact definition for droughts. In various literature sources it is possible to find even more than 150 definitions of a drought (Gibbs, 1975; Krishnan, 1979, Dracup et al., 1980; Wilhite and Glantz, 1987). Darcup et al. (1980) maintain that the major problem is that the drought as such is understood differently in various regions with different climate, and in different countries. It should also be noted that the definitions/concept of a drought varied and changed not only between various regions and countries, but also historically. And in some countries, there is no concept unified and acceptable to everyone and drought definition is still under intensive consideration and dispute.

It is important to separate droughts from aridity. The aridic zones have certain established dry periods, and droughts are formed as a negative deviation of precipitation volume from the mean (Coughlan, 1985). Droughts, differently from aridity, are temporal phenomena and they are not permanent, nor regular (Hisdal and Tallaksen, 2000).

D. A. Wilhite and M. H. Glantz (1985) indicated that one of the major problems is that there is no unified and widely acceptable drought classification scheme, and they tried to clarify droughts into certain groups. Having analysed more than 150 definitions of droughts found and published in various sources of literature up to the year of 1980, they grouped them into 4 categories: meteorological, agrometeorological, hydrological, and socioeconomic. This grouping of droughts into 4 categories became popular worldwide; today it is widely accepted and commonly used.

Meteorological droughts. These are prolonged dry weather conditions with the precipitation being lower than usual. The meteorological drought forms earlier than other types of droughts (Alliance for Water..., 2010). Thus, the meteorological drought usually depends only from amount of precipitation and the devation of this amount from normal conditions.

Agrometeorological droughts start when the humidity in soil decreases to such a level when the amount of water needed for the vegetation of plants becomes insufficient. This is related not only to precipitation, but also to evaporation. Other criteria are also important: air temperature, air humidity, wind speed, soil type, and plant types. As a rule, an agrometeorological drought is being formed with the existence of the meteorological drought (Hayes, 2006; National Drought…, 2013).

Hydrological droughts. They form when after a certain long period of precipitation deficit the water level of surface or groundwater sources falls down to certain and defined dangerous level. Usually this type of drought is formed when the meteorological and agrometeorological droughts already exist (Hayes, 2006; National Drought…, 2013).

Socioeconomic droughts. The type of socioeconomic droughts is related to the meteorological, agrometeorological and hydrological droughts impact and their damages to economic, social and environmental sectors.

Droughts are usually characterized by three major characteristics: duration, intensity, and extend territory (Wilhite et al., 2000). Droughts are also defined on the basis of their impact which depends on the vulnerability of the territory to droughts.

After the restitution of independence of Lithuania, the concept of a drought was taken over from the former USSR. In the USSR droughts have been divided into atmospheric, soil, and mixed-type. This concept and drought categorization prevails till now.

The essential difference which separated the concept of a drought used in Lithuania from the concepts most used worldwide is that droughts in our country are usually related to the warm period of the year, and this eliminates possibility of droughts e.g. in winter. In Lithuania, droughts during winter time were not investigated at all because only the vegetation period of plants and the agriculture were subjects for investigation.

Despite the fact that the concept of drought in Lithuania is till related to the agrometeorological droughts, the analysis of meteorological and hydrological droughts already started.

In Lithuania, the official drought index, on the basis of which are presently identified and announced droughts is the hydrothermal coefficient of Selianinov (HTC). Following the order of the Minister of Environment, dated November 11, 2011, "For the Approval of Extreme, Catastrophic Meteorological, and Hydrological Phenomenon Indicators", droughts, during the active plant vegetation periods are announced as extreme meteorological phenomenon when the average daily air temperature is ≥10 °C, and hydrothermal coefficient for >30 days in turn is <0.5 (Lietuvos Respublikos…, 2011).

2. METHODS

Droughts differ from other hazardous meteorological phenomena because it is impossible to express or measure droughts in any conventional measurement units. This is why indices are used to identify and define droughts based on certain measurable data to enable to define dry conditions at certain places and/or certain periods (Hisdal and Tallaksen, 2000).

A drought is announced when certain index values exceed a certain limit or drought duration, in other words, when a certain drought criterion is reached (index limit values are defined by the calculation methods of the index itself).

In this thesis, SPI and HTC were used to evaluate the meteorological drought, and the SRI – for the hydrological drought. The thesis also covers the inter-relation of the indices used, provides the evaluation of the possibilities to employ the measured soil moisture for the definition of the agro-meteorological droughts. It also covers the impact of the socioeconomic drought to the economy, environment, and social sectors.

Analysis of drought and dryness dynamics in Lithuania and the Baltic Sea region

The SPI was used for the assessment of meteorological droughts and dry periods in Lithuania and the Baltic Sea region. The SPI calculation for any location is based on monthly rainfall data series, first applying gamma distribution and then transforming it into a normal distribution (McKee et al., 1993; Edwards and McKee 1997). Positive SPI values indicate greater than average precipitation amounts and negative values indicate lower amounts. Based on the SPI value, dryness of the area can be evaluated (Table 1).

Table 1. Interpretation of SPI values (WMO, 2012).

Value	*Interpretation*
≥2.0	Extremely wet
1.99– 1.5	Very wet
0.99 – −0.99	Near normal
-1.0 – −1.49	Moderately dry
-1.5 – −1.99	Severely dry
≤−2.0	Extremely dry

The beginning of drought can be fixed when the SPI value falls below −1.0 and the end of the drought can be determined when the index value becomes positive. Intensity of drought should be calculated as a sum of all the SPI values during the drought period (McKee et al. 1993). The SPI can be calculated for different time steps. Monthly precipitation data has been used from 17 meteorological stations and 15 stations with precipitation observation (further − MS) for meteorological drought assessment in Lithuania (Fig. 1). SPI was calculated from monthly precipitation data during the observation period of 1961–2010. Drought and dry periods analysis according to SPI was done using different timescales: SPI1, SPI3, SPI24. One-month time step (SPI1) means that only one-month precipitation data are used for calculation. For the calculations of SPI3, three-month precipitation data are used, i.e. the data of the month for which SPI3 is calculated and the data of the previous two months. The calculation of SPI24 covers the month for which it is calculated and the precipitation amount of the previous 23 months.

The annual and summer drought dynamics were analyzed separately. The cluster analysis has been employed for the purpose to assess the dynamics of drought duration and intensity in different parts of the investigated territory. Three regions with different dryness regime have been distinguished (Fig. 1). The north east part of the Lithuania was attributed as the first region, south east of territory as the second region and west part of Lituania as the third region (Fig. 1). SPI values of meteorological station in each cluster were averaged to a single value for the whole region.

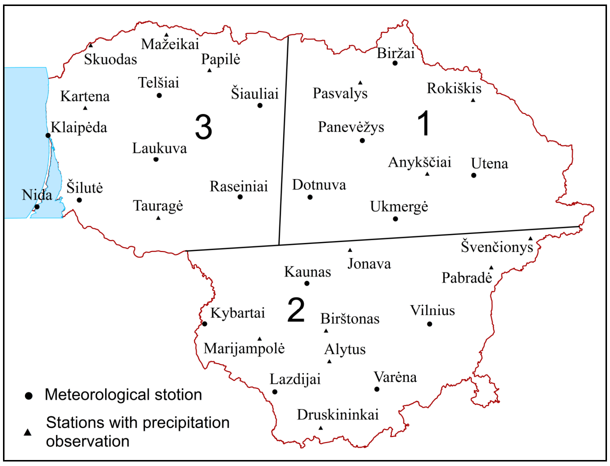

Fig 1. Meteorological stations which precipitation data were used and three regions distinguished using cluster analysis according to SPI.

According to SPI1, SPI3 and SPI24 indices some climatic parameters of drougts were calculated: a) the number of droughts and their duration during 1961–2010 period; b) the mean one drought duration (in month); c) the mean drought intensity; d) total number of all droughts months (sum of all drought months); e) total intensity (sum of all droughts intensity); f) the most intensive drought; g) number of extreme dry months (months then SPI values is ≤−2).

Vilnius meteorological station was selected to assess long-term dryness condition dynamic in Lithuania. This station has longest precipitation measurement data series in Lithuania. SPI was calculated from monthly precipitation data during the observation period of 1891–2010 using SPI1, SPI3, SPI6, SPI9, SPI12, SPI24, SPI48, SPI60 indices.

In this study drought dynamics in the Baltic Sea region (further – BSR) covers the territory on 50.25°–70.25° N and 10.25°–30.25° E which includes the whole of the Baltic Sea area and surrounding countries (Fig. 2). The fifty-year period of observation from 1960 till 2009 has been covered. Gridded data from the regular 105 grid points at 1-degree resolution in the BSR have been used (Fig. 2). Monthly precipitation amount data from Climate Research Unit (CRU) at the University of East Anglia has been used. Droughts and dry periods in the BSR were identified using SPI3, SPI12, SPI60 indices.

The cluster analysis has been employed for the purpose to assess the dynamics of drought duration and intensity in different parts of the investigated territory. Four regions with different dryness regime have been distinguished (Fig. 2).

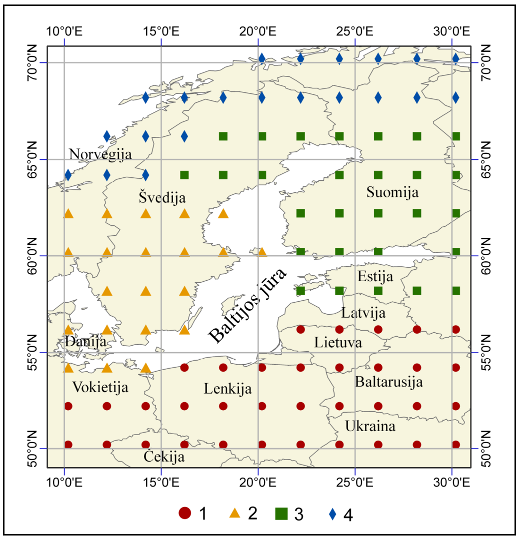

Fig. 2. The parts of the BSR's distinguished using cluster analysis according to SPI dynamics during the observation period of 1960–2009.

The drought intensity is calculated as a sum of SPI3 values during the droughts. The correlation analysis has been used to choose grid points which reflect the average characteristics of dryness dynamics in each cluster best.

The annual and summer drought dynamics are analyzed separately.

The Mann-Kendall test has been performed to evaluate the statistical significance ($\alpha \leq 0.05$) of SPI values trends.

Changes of dryness for the 21st century according to SPI in Lithuania and the BSR.

Regional climate model CCLM (*COSMO Climate Limited – area Model*) output data was used in this research for the purpose to investigate possible changes of SPI values in the 21st century. Projections of future dryness are based on the precipitation output data driven by A1B and B1 emission scenarios.

Modelling outputs are presented for two periods: a control run (1960–2000) and two scenario runs (2001–2100). CCLM model data outputs were taken from the CERA data base which was driven by WDCC (World Data Center for Climate).

CCLM model control run data for the grid points which correspond to the CRU database grid points differ quite a lot. CRU and CCLM precipitation data have been compared for the overlapping period 1960–2000. The determined ratio between mean monthly precipitation values has been used to make the climatic forecast.

Changes of dryness for the 21st century was done using SPI1, SPI3, SPI24 indices in Lithuania and SPI3, SPI12 indices in the BSR.

Droughts analysis in Lithuania according to HTC.

The official criteria for identification of drought in Lithuania is hydrothermal coefficient (HTC) of Selyaninov. Although mostly HTC is assigned to the meteorological drought indices group, in Lithuania this index is used as agrometeorological drought indicator.

HTC has been calculated by using formula of G.Selyaninov (Selyaninov, 1928).

$$HTK = \frac{P}{0{,}1\sum t_{10}}; \qquad (1)$$

where P – the sum of precipitation (mm) during the given period, t_{10} – the sum of the average daily temperatures higher as 10 °C during the same period.

Values of the HTC was calculated for the growing season (when mean air temperature is higher than 10 °C). HTC was calculated daily, each value was calculated from the sum of the precipitation and the mean air temperature data of the 29 previous and the current day. Drought − 30 days or longer periods with HTC<0,5 (table 2).

Table 2. Interpretation of HTC values (LHMT, 2013).

Value	*Interpretation*
>1.6	Wet conditions
1.0–1.5	Optimally wet
0.8–0.9	Weak drought
0.6–0.7	Medium drought
<0.5	Severe drought

According to HTC, extreme droughts in Lithuania during 1961-2010 period were identified.

Drought can be local (when it is registered in one or few meteorological stations) and country-wide drought which covered more than 1/3 Lithuanian territory (Klimato žinynas, 2000).

Daily precipitation and air temperature data from 18 meteorological stations were used in this research. The analyzed period covers 1961-2010. Air temperature and precipitation deviation from the normal was calculated during all extreme droughts.

Evaluation of the data on the potential applications of soil moisture for the identification of agrometeorological droughts in Lithuania

One of the possibilities to identify agrometeorological drought is the use of information on soil moisture from agrometeorological stations (AGMS). The 2011-2013 period was analyzed in order to assess how the HTC value calculated on daily base coincides with the soil moisture W (cbar), measured on the same day at a 20 cm depth in the agrometereological station. Each day during the summer months was assessed in two agrometereological stations characterized by different soil types: Biržai and Varėna.

Hydrologycal droughts analysis in Lithuania according to SRI

Hydrological droughts in this study has been defined using SRI (Standartized Runoff Index) proposed by S. Shukla and A. W. Wood (2008) by applying the SPI algorithm to runoff data. Interpretation of SRI values is the same as interpretation of SPI values (1 table).

Four rivers basins (Jūra, Merkys, Šešupė, Šventoji) (Fig. 3) were analyzed for evaluation of hydrological droughts. Runoff data from four hydrological stations (further – HS) were used for SRI calculations. Analyzed period covers 1961–2010.

Jūra. River length is 172 km. Runoff data from Tauragė HS was used (catchment area up to Tauragė HS – 1690 km ^{2}). The Jūra is fed by rainfall (50 % of the annual runoff), spring snowmelt waters (30 %), and groundwater (20 %).

Merkys. River lenght is 203 km. Runoff data from Puvočiai HS was used (catchment area up to Puvočiai HS – 4300 km ^{2}). Groundwater accounts for 63 % in the annual runoff of the Merkys at Puvočiai. Sands cover 67 % of the Merkys basin area.

Šventoji. River length is 246 km. Runoff data from Ukmergės HS was used (catchment area up to Ukmergė HS – 5440 km ^{2}). The river is fed by groundwater (40 %), snowmelt (32 %), and rainfall (28 %).

Šešupė. River length is 298 km. Runoff data from Kudirkos Naumiestis HS was used (catchment area up to Kudirkos Naumiestis HS – 3210 km ^{2}). The Šešupe near

Kudirkos Naumestis is fed by snowmelt (37 %), rainfall (36 %), groundwater (27 %) (Kilkus, Stonevičius, 2011).

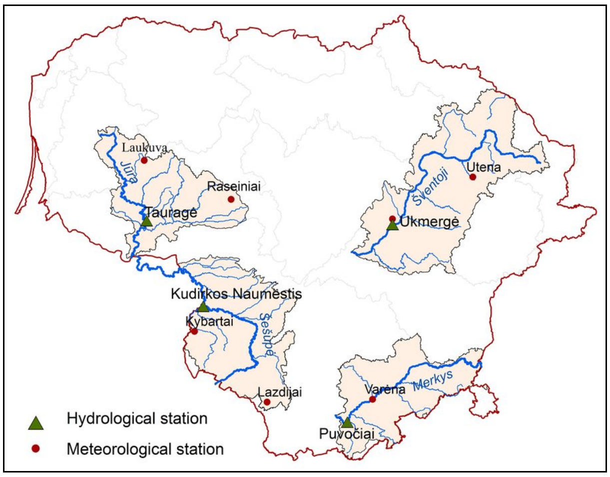

Fig. 3. Rivers basins, which data were used in this study.

Hydrological droughts have been defined using four time steps: SR12 calculated for September, SRI4 calculated for September, SRI3 calculated for July and October and SRI1 calculated for June, July and August.

SRI12 was used to calculate the total annual discharge starting from the beginning of the hydrological year (i.e. October).

SRI4 was calculated by using the four months (June–September) average discharge. It's a four-month warm period of the year when influence of the spring floods and early autumn ice phenomena in rivers is eliminated.

SRI3 was calculated by calculating the three-month average discharge of warm period of the year. According to this time step only non-overlapping 3-month SRI values used to analyzed hydrological drought dynamics: May–July and August–October.

SRI1 has been calculated to define hydrological drought during summer months.

Methodology for comparison of drought determined by different drought indices

In order to compare the values according to SPI and HTC indices and the parameters of drought, identified by the aforementioned indices, HTC values were calculated for summer months for 1891–2010 in Vilnius MS, and then they were compared with SPI1 values. Moreover, the total value of summer HTC (i.e. for the period of three months) was found, and later compared with SPI3 value for August.

In order to compare the values according to SPI and SRI indices and extreme droughts, identified by these indices, the period of 1961–2010 was investigated. The values of time steps of SRI1, SRI3, SRI4 and SRI12 of all months of the analyzed period were compared with SPI values of the same time steps.

Assessment of socioeconomic impact of drought in Lithuania

The research analyzed the socioeconomic impact of drought on agriculture, forest fires, river navigation. It also shortly reviewed the impact of drought on land transport infrastructure, recreation and tourism, hydropower, human health, and wildlife.

3. RESULTS

3.1. Dryness dynamics of Lithuania and the Baltic Sea region

Dryness dynamics for the 1961-2010 period in Lithuania

The analysis of dryness dynamics in the Lithuania for 1961–2010 shows statistically significant positive changes of annual SPI values for different time steps. It means that during the analyzed period the all three regions have received the increased amount of moisture. In summer months changes of SPI values were also positive, but statistically significant only according to SPI24 in south east of Lithuania.

SPI dynamics of the meteorological stations assigned to a certain region (north-eastern, south-eastern, and western) not always coincide with general changes in the whole region. The SPI value calculated in particular meteorological stations may also be affected by specific physical geographical conditions.

There were found changes of the SPI1 to be positive in all Lithuanian meteorological stations. Statistically significant positive changes were identified in majority of meteorological stations (Fig. 4A). During the summer months almost all stations also showed positive changes according to SPI1. However, in this case the changes were not statistically significant (Fig. 5A).

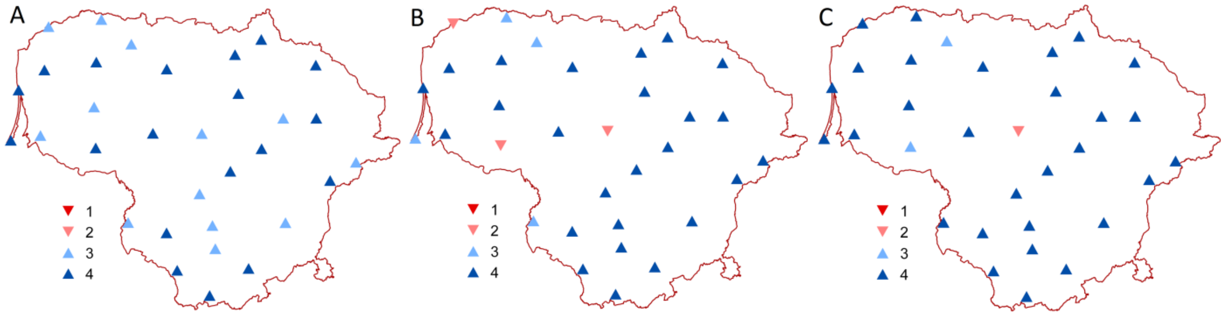

Fig. 4. The sign and statistical significance (α = 0.05) of observed SPI tendencies for 1961–2010 in the Lithuania, according to: A) SPI1 annually, B) SPI3 annually, C) SPI24 annually. 1 – Significant positive changes; 2 – insignificant positive changes; 3 – insignificant negative changes; 4 – significant negative changes.

Positive and statistically significant annual SPI3 tendencies were identified in the large part of Lithuania (Fig 4B).

Positive, but statistically insignificant changes of SPI3 values in summer were identified in the whole Lithuania (except one MS in the central part of the country) (Fig. 5B).

Positive and statistically significant tendencies were also identified in the large part of Lithuania according to annual SPI12 values (Fig. 4C). Changes of SPI12 values in summer were also positive, however they were statistically insignificant in the large part of country (Fig. 5C).

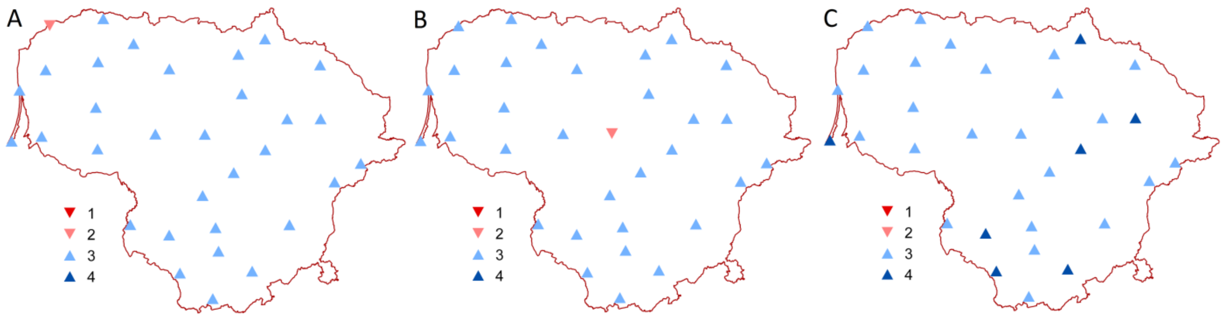

Fig. 5. The sign and statistical significance (α = 0.05) of observed SPI tendencies for 1961–2010 in the Lithuania, according to: A) SPI1 summer, B) SPI3 summer, C) SPI24 summer. 1 – Significant positive changes; 2 – insignificant positive changes; 3 – insignificant negative changes; 4 – significant negative changes.

The main parameters of a meteorological droughts in all three regions of the country are presented in Table 3. The registered number of extremely dry months and droughts in the regions is different, while theoretically (the SPI values are distributed according to a normal distribution) it should be the same. This happens because of several reasons:

a) The amount of precipitation accumulated during a different number of months is not perfectly distributed according to the Gamma distribution. Therefore, some distinctions may occur while normalizing the Gamma distribution.

b) Drought begins when the SPI value falls below -1 and ends when the index value becomes positive. Thus, the number of drought months may vary, because during a single drought a few months may be registered, when $-1<SPI<0$.

c) While identifying a drought according to large SPI time steps, certain inertia occurs, because one month with high level of precipitation will not be the reason to register the end of a drought.

The change of drought intensity during the drought vary a lot, and the peak can be reached at any time during a drought. However, the first half of a drought is typically characterised by a higher intensity than the second half.

Table 3. The main characteristics of the droughts according to SPI during 1961–2010 in Lithuania.

	SPI1			SPI3			SPI24		
	Region			Region			Region		
	I	II	III	I	II	III	I	II	III
Total number	59	61	55	37	30	32	5	7	6
Mean duration (months)	2.2	1.9	2.3	4.2	5.0	4.8	27.6	17.9	26.3
Mean intensity	−2.5	−2.3	−2.7	−4.5	−5.0	−5.1	−28.0	−17.5	−27.4
Number of extremely dry months	14	13	16	7	5	12	10	5	6
Max duration in months	10	5	11	12	17	11	50	33	58
Max intensity	−10.6	−7.8	−8.5	−13.9	−10.4	−14.8	−52.9	−34.3	−64.3
Total intensity	−147.1	−138.2	−146.4	−166.4	−149.8	−164.1	−139.8	−122.8	−164.2
Total number of droughts months	130	117	128	155	148	154	138	125	158

I region – North East; II region – South East; III region – West.

Sometimes a drought may last for many months, but in the same time may not be intensive, and during a such drought no EDM (Extremely Dry Month: SPI value falls bellow −2) are recorded. As we can see in Table 3, the total number of droughts is quite significant. A large part of these droughts (especially those short and of low intensity) do not have a greater influence on our country, they pass almost unnoticed and do not cause any higher damage.

It was found that according to SPI24 most of the EDM were registered during the first half of the analyzed period, i.e. 1961–2010, and, in the case of SPI1, such summer months were more common during the last two decades of analyzed period. In other words, the number of short and severe droughts during the summers have increased.

The slight decline in dryness have been found over the last fifty years (1961–2010) in all parts of Lithuania according to all SPI time steps. This tendency is more clearly expressed in long time steps of SPI values. However, the number of extreme dry months according to SPI1 during vegetation period increased during second part of analyzed period.

According to SPI1 value, the most extreme droughts in Lithuania were recorded in November 1993 and July 1994, while almost the whole territory has reached a critical level of −2 (extremely dry). Whereas from economic point of view the summer droughts are the most important. Therefore the drought of July 1994 can be considered as the most dangerous.

According to SPI3, the most extreme drought was recorded in January 1969. Because this drought was recorded in winter, the most extreme drought in summer was observed in July 1992. This drought started from May and reached the maximum values in the middle of the summer.

According to SPI24, the most extreme drought was recorded in January 1977. This drought due to low precipitation amount in a large part of the Lithuania started from autumn at 1976. Later drought intensified and in the most meteorological stations reached the maximum values in January 1977. The end of the drought registered only in autumn 1978.

Dryness dynamics for 1891-2010 period in Vilnius

According to all SPI time steps, positive statistically significant tendency has been identified. This tendency is more clearly expressed in long time steps of SPI values.

The driest summer months were observed in the first thirty years of the analyzed period (in 1891–1920) according to SPI3, SPI6, SPI9, SPI12, SPI48, SPI60, while according to SPI1, the driest months were recorded in the last thirty years of the analyzed period.

Dryness dynamics for 1960–2009 in the Baltic Sea region.

The analysis of the drought dynamics for 1961–2010 in the BSR shows increased SPI values for different time steps. The most notable changes have been observed at long time steps (Fig. 6B). The first part of the analyzed period can be described as a period with especially low SPI60 values. The positive changes of the three-month long dry periods (SPI3) were not so significant (Fig. 6A). It means that, the probability of short-term droughts remains quite high on the background of the overall decline in dryness.

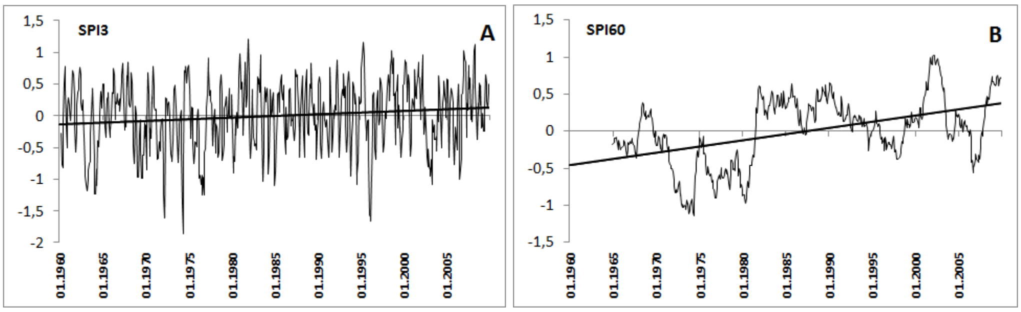

Fig 6. Dynamics of dryness for 1960–2009 in the BSR according to SPI3 (A) and SPI60 (B).

According to SPI3, 31 cases when more than half of the analyzed area reached moderately dry condition (SPI3< −1) have been identified during the 1960–2009. In five cases such conditions were observed in the area covering more than two-thirds of the region.

The most extreme drought in the BSR was recorded in May 1974 with the average SPI3 value falling to −1.86, while nearly half of the territory has reached a critical level of −2 (extremely dry) (Fig. 7A).

During the analyzed period, 8 cases have been distinguished with SPI3 values being less than −1 (moderately dry) in more than half of the analyzed area in summer. The most intense summer drought was recorded in August 1976 (Fig. 7B).

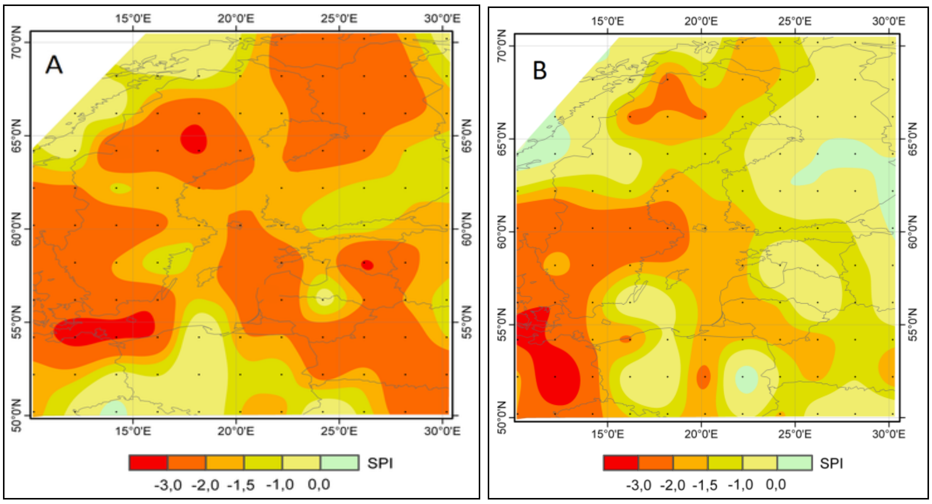

Fig 7. Spatial distribution of SPI3 values during extreme droughts of May 1974 (A) and August 1976 (B).

It should be pointed out that tendencies in dryness vary in different parts of the region (Fig. 8A, 8B).

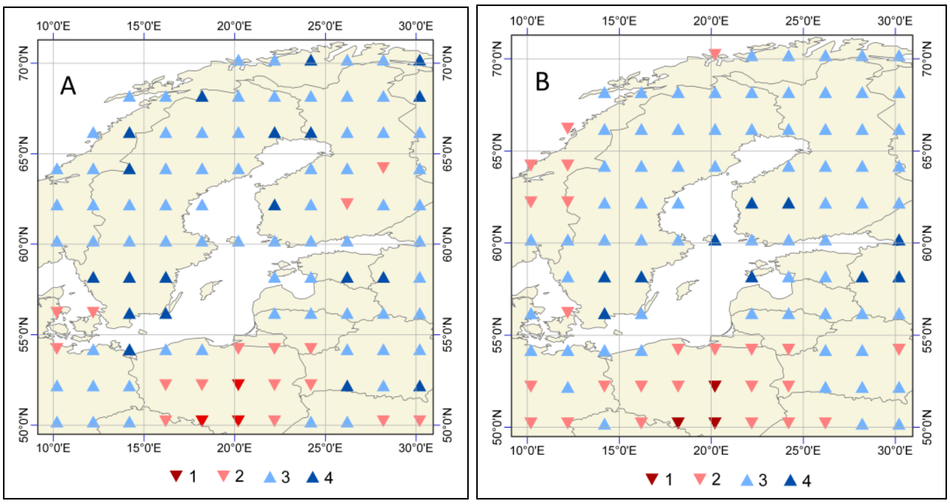

Fig. 8. The sign and statistical significance (α = 0.05) of observed SPI values tendencies for 1960–2009 in the BSR according to SPI12 annually (A) and SPI3 in summer (B). 1 – Significant positive changes; 2 – insignificant positive changes; 3 – insignificant negative changes; 4 – significant negative changes.

A slight tendency for the draught intensification was observed in the first region (Fig 2). The drought intensity in the rest part of the region decreased. Such change have been particularly strong in the North (Region 4) (Fig. 9D). The number of years when the SPI3 value did not fall below -1 has increased significantly over the past two decades in the second and fourth regions (Fig. 9B, 9D). The second region has recorded the strongest annual sum of drought intensity (−15.3 in 1976). The driest years in other regions were observed during 1960s, when the total annual intensity of the drought has fallen below −10 (Fig. 9A, 9C, 9D).

Other investigations also shows decrease in drought recurrence is found by using other methods in different parts of the BSR (Mager et al. 2000; Hisdal and Tallaksen 2003; Tammets 2007; Jakimavičiūtė and Stankūnavičius 2008; Avotniece et al. 2010; Samaniego et al. 2011). Agrometeorological drought recurrence shows negative trends (Schindler et al. 2007; Daugėlienė and Žekonienė 2009; Tammets 2010; Kaznowska 2011), as does the hydrological one (Hisdal et al. 2001; Stonevičius et al. 2006; Kriaučiūnienė et al. 2007; Klavinš et al. 2008; Wilson et al. 2010; Gailiušis et al. 2011) in the BSR.

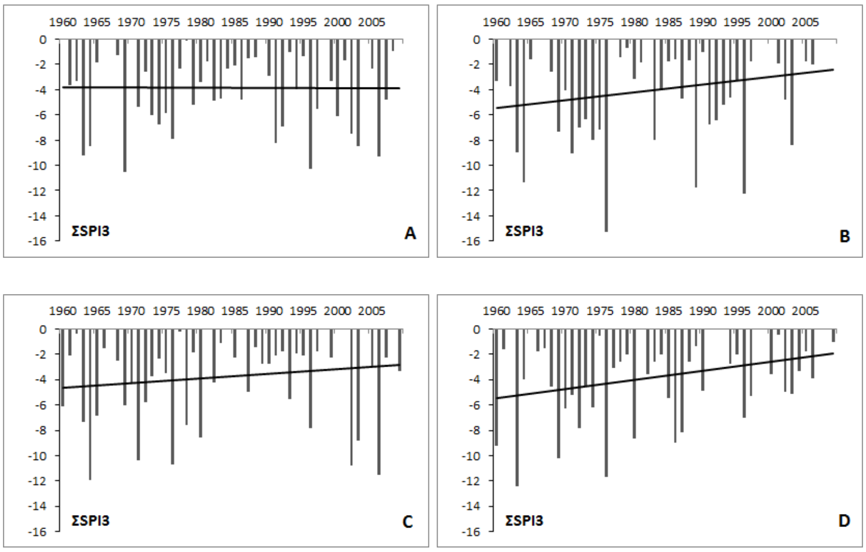

Fig 9. Dynamics of drought intensity for 1960–2009 in different BSR’s according to SPI3 (data from regular grid points of CRU database): A) region 1 (54.2° N; 24.2° E); B) region 2 (58.2° N; 14.2° E); C) region 3 (62.2° N; 24.2° E); D) region 4 (70.2° N; 24.2° E).

The analysis of results suggests that meteorological drought occurrence has either remained the same or has decreased during the 20th century, although some positive trends have been found for sites in Denmark and in Latvia (BACC 2008). However, severe droughts might still occur in every part of the region (van Lanen et al. 2007; Graham et al. 2009; Tallaksen and Stahl 2012).

3.2. Projected changes of dryness for the 21st century

Projected changes for Lithuania

It is forecasted that in the 21st century dryness tendencies in Lithuania will be similar to observed in 1961–2010 period.

Positive annual SPI1 tendencies during 21st century in Lithuania are expected under both (A1B and B1) climate scenarios, but statistically significant changes are predicted only for the west part of the country (Fig. 10A).

Meanwhile, the negative and in many cases statistically insignificant changes of SPI1 values in summer months (the increase of summer dryness) are expected under A1B climate scenario in all Lithuania (Fig. 11A).

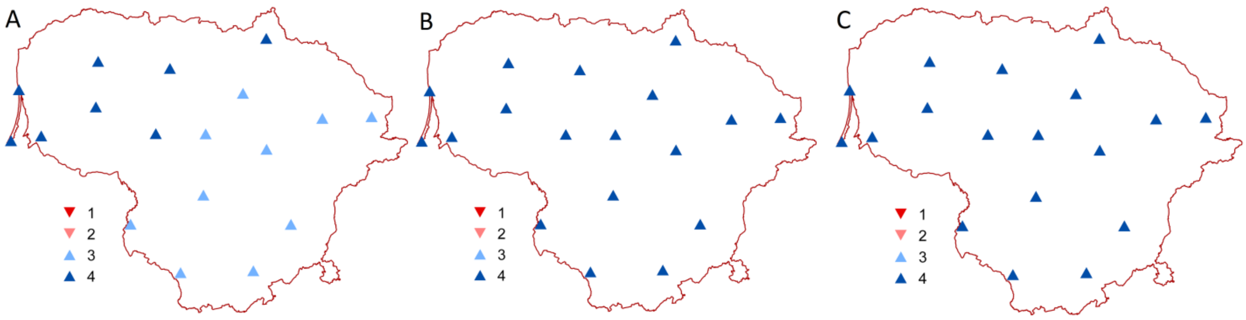

Fig. 10. The sign and statistical significance (α = 0.05) of SPI tendencies in Lithuania in 21st century simulated using the CCLM model output data based on B1 emission scenarios: A) SPI1 annually; B) SPI3 annually; C) SPI24 annually. 1 – Significant positive changes; 2 – insignificant positive changes; 3 – insignificant negative changes; 4 – significant negative changes.

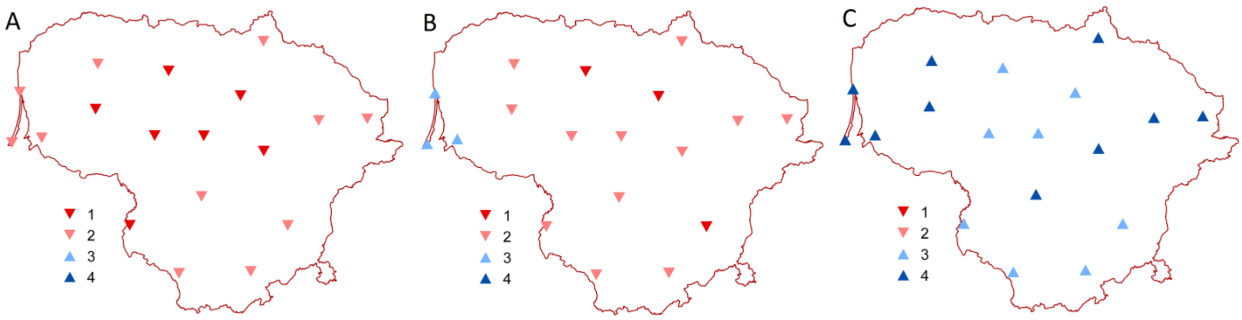

Fig. 11. The sign and statistical significance (α = 0.05) of SPI tendencies in the Lithuania in 21st century simulated using the CCLM model output data based on A1B emission scenarios: A) SPI1 summer; B) SPI3 summer; C) SPI24 summer. 1 – Significant positive changes; 2 – insignificant positive changes; 3 – insignificant negative changes; 4 – significant negative changes.

It is predicted that in the second half of the 21st century droughts according to SPI1 during the warm season will be more frequent than in cold season.

Positive annual SPI3 tendencies in the Lithuania are expected under both climate scenarios. Statistically significant changes are predicted in whole Lithuania under B1 climate scenario (Fig. 10B) and in the part of Lithuania under A1B climate scenario.

Positive SPI3 changes in summer months are expected under B1 climate scenario in the whole territory. Meanwhile under A1B climate scenario positive SPI3 changes are expected only in the coastal area of Lithuania. Negative and in many cases statistically insignificant changes are forecasted in the remaining part of the Lithuania (Fig. 11B).

Positive annual and summer SPI24 tendencies will be statistically significant in the whole Lithuania under B1 climate scenario and almost in whole territory under A1B climate scenario (Fig 10C, 11C).

Predicted drought dynamics is quite similar to predicted changes in the precipitation regime of the 21st century. A forecast based on B1 climate scenarios shows that the mean precipitation amount will increase during the 21st century in all parts of Lithuania. The biggest changes are expected in the western part of Lithuania. Meanwhile according to A1B climate scenario some negative trends can be observed. Precipitation will increase in winter and spring, and will decrease in summer and autumn (Rimkus et al. 2009).

Projected changes for the Baltic Sea region

Predicted positive SPI12 tendencies will be statistically significant almost in the whole territory (Fig. 12A and 12B). Statistically insignificant negative changes are predicted only for the most southern part of the BSR. Moreover, the observed tendencies will remain or even will intensify in the future. On the other hand, the area with negative changes determined during the observation period will decrease. Meanwhile, in the summer months such area will be much larger. Especially it will be evident according to the A1B climate scenario (Fig. 12C). Negative trends will be significant in many locations.

The increase in summer dryness only in the most southern part of the BSR is expected under the B1 climate scenario (Fig. 12D). Positive and in many cases statistically significant changes of SPI3 values are foreseen in the remaining part of the territory. The largest changes have been projected for the most northern part of the region.

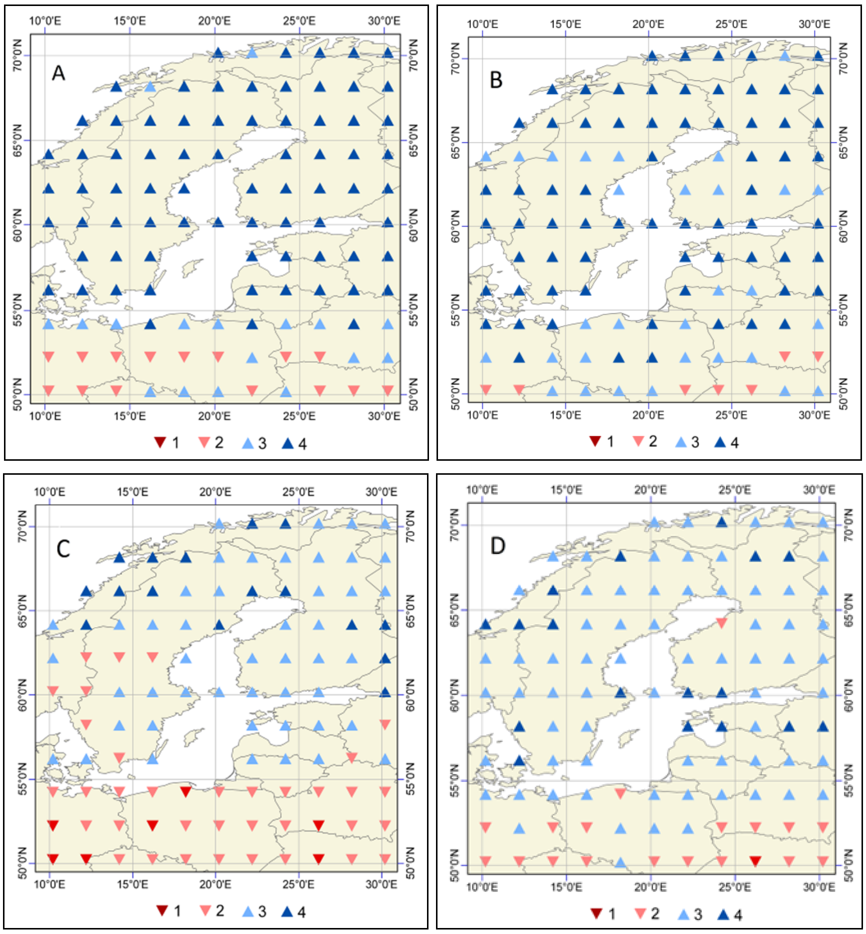

Fig. 12. The sign and statistical significance (α = 0.05) of SPI tendencies in the BSR in 21st century according to SPI12 annually and SPI3 in summer and simulated using the CCLM model output data based on the A1B and B1 emission scenarios: A) A1B annually; B) B1 annually; C) A1B summer; D) B1 summer. 1 – Significant positive changes; 2 – insignificant positive changes; 3 – insignificant negative changes; 4 – significant negative changes.

According to both climate scenarios, the intensity of droughts in the 21st century will likely decline almost in the whole researched area. The most significant changes are foreseen for the North (Region 4) (Fig 13A.). It should be noted that not only the decline in recurrence of extreme dry years will be observed, but also the increase in number of years without droughts according to SPI3 is expected (Fig. 13A). The increase in intensity of droughts is foreseen only in the south-western edge of the BSR. This is mainly due to the projected rainfall decrease during the summer months (Fig. 13B).

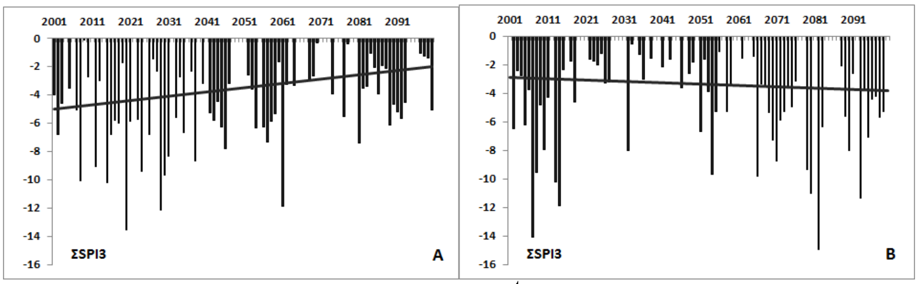

Fig 13. Dynamics of drought intensity in the 21st century (according to SPI3) in different BSR's simulated using the CCLM model output data according to the A1B emission scenario A) region 4 (70.2° N; 24.2° E); B) region 1 (50.2° N; 20.2° E).

The paper results are similar to the findings of other authors in the BSR (Raisanen et al. 2003; BACC 2008). The drought recurrence in the major part of the region tends to decrease throughout the 21st century. Only the most southern parts of the region seem to be characterised by the drought recurrence tending to increase in the future. These trends are similar to temperature and precipitation projections in the Central and Southern Europe (Kjellstrom et al. 2007; Fischer and Schar 2009). Because of growth in summer air temperatures, the recurrence and intensity of droughts may increase (IPCC 2007; BACC 2008). Previous studies have shown that the number of heavy precipitation events will increase in some parts of the region (Christensen, Christensen 2004; Beniston et al. 2007; Kjellstrom, Ruosteenoja 2007; Rimkus et al. 2011). It should be noted that an increasing part of precipitation will fall in a form of short-term but very intensive rainfall which often will be followed by dry periods. Meanwhile, the drought recurrence in the BSR will be relatively lower, but the drought will be more severe and could be evident in every part of the region in the 21st century (Dankers, Hiederer 2008; van der Linden, Mitchell 2009).

3.3. Identification of drought according to HTC for 1961–2010 in Lithuania.

In order to assess drought according to HTC, it is necessary to know the length of the period of active plant vegetation. Active plant vegetation proceeds when the average air temperature is >10 °C.

The average length of the period of vegetation in Lithuania is 147 days. A statistically significant increase of the vegetation period during the analyzed period was determined.

Extreme drought in Lithuania

According to HTC extreme droughts were identified in 13 years (table 4) during the period from 1961 to 2010.

Local extreme droughts were registred during the seven years. Extreme droughts which covered more than 1/3 of Lithuanian territory (country-wide droughts) were registered six times. Analysis showed that during last two decades droughts become more frequent and covered larger territories. During the last two decades 5 country-wide droughts were registered. In these five cases, two droughts (1992 and 1994) covered ≥2/3 of the country (table 4).

Table 4. Extreme droughts events according to HTC for 1961–2010 in Lithuania.

Year	Meteorological station
1964	Dotnuva, Lazdijai, Panevėžys, Ukmergė
1967	Kaunas, Nida
1969	Kybartai, Utena
1971	Kaunas, Lazdijai, Varėna
1974	Nida
1975	Biržai, Klaipėda, Laukuva, Nida, Šilutė, Telšiai
1983	Kybartai
1992	Dotnuva, Dūkštas, Kaunas, Klaipėda, Kybartai, Laukuva, Nida, Panevėžys, Raseiniai, Šiauliai, Šilutė, Utena, Vilnius
1994	Biržai, Dotnuva, Kaunas, Klaipėda, Kybartai, Lazdijai, Laukuva, Nida, Panevėžys, Raseiniai, Šiauliai, Šilutė, Telšiai
1996	Biržai, Laukuva, Nida, Šiauliai, Ukmergė, Utena
2002	Biržai, Dotnuva, Dūkštas, Kaunas, Klaipėda, Kybartai, Lazdijai, Laukuva, Panevėžys, Raseiniai, Šiauliai
2005	Šiauliai,
2006	Dotnuva, Klaipėda, Nida, Panevėžys, Šiauliai, Šilutė, Ukmergė, Telšiai

The number of droughts registered in specific meteorological stations during the analyzed period of 50 years has varied between 1 in Varėna and Vilnius, and 7 in Nida.

Analysis showed that droughts were more frequent in western and south-western parts of the country, and rarer in the south-eastern and eastern Lithuania.

Air temperature during droughts was on average 1.8 °C higher than the mean temperature for the same period. Amount of precipitation during recorded severe droughts varied from 10 to 46 % of the average amount of precipitation for the same period.

The duration of severe droughts in 1961–2010 in Lithuania varied from 31 to 73 days. The longest severe drought was recorded in Utena in 1992. It lasted from 11th of June to 22nd of August.

This paper revealed disadvantages of drought identification according to HTC.

1. The concept of drought itself in Lithuania is associated with drought during active vegetation period. HTC describes hydrothermal conditions of same period of the year. However, when only active vegetation period is taken into account, early spring droughts can't be considered. At least 61 days must pass from the start of growing season, in order extreme drought to be announced. Moreover, data on soil moisture are not included into calculations of this index. Therefore, HTC alone, as agrometeorological drought indicator, is not suitable for Lithuania.

2. One of the HTC calculation problems is the fact, that in case of different calculation methodologies, the obtained results can differ too. Different methodologies for HTC calculation were used in Lithuania. Currently, HTC is calculated from the period of thirty days, shifting each next day forward by one day (by keeping the thirty days period). It is recommended to continue following this methodology.

3. Sometimes HTC overestimates the amount of precipitation. For example, in 1969, there was no recorded extreme drought in Šilutė, however, there were two dry periods: the duration of one of them was 21 extremely dry days (EDD), of another one – 28 EDD. The interval between these two periods was 12 days. If there had been at least 2 mm less precipitation, there would have been no interval between two extremely droughty periods. Extreme drought of 61 days would have been recorded. In this case, severe (extreme) drought was not recorded in Šilutė, however, the aforementioned situation is not less dangerous to agriculture than severe drought lasting for 31 days.

4. As a result of the fact, that the start of the active vegetation period is recorded at different times in different MS, HTC cannot be started to be applied at the same time across Lithuania, and this is quite significant disadvantage of HTC application. The problem is especially evident when drought starts together with start of the active vegetation. Drought calculation sometimes ends together with the end of the active vegetation period.

While solving this problem, HTC calculation could be started and ended in all MS at the same time, if the start and end dates there differ by no more than 15 days and the mean air temperature of the considered period of 30 days is >10 °C.

5. HTC calculations are related with precipitation and air temperature. However, the end of severe drought should be recorded only when precipitation falls and not when air temperature decreases.

6. Extreme drought of local significance occurs when it is recorded in one or several MS, while in case of severe drought covers ≥1/3 of the territory of Lithuania, it can cause a country-wide disaster. While recording droughts, most questions arise, when extreme droughts are recorded at different times in various meteorological stations.

If an extreme drought is recorded in one third and more MS at different times during growing season, it should be considered that local extreme droughts were present that year. However, the losses, caused by these local extreme droughts, are country-wide.

When an extreme drought is officially announced, the farmers have the possibility to receive insurance payments for their lost crops. Therefore, in case HTC is continued to be used for drought identification in Lithuania, the criterion of definition of extreme drought should be broadened. The definition of extreme drought could be as follows: *"Extreme drought is recorded when HTC value is <0.50 for >30 days in a row during growing season; or when HTC value is <0.50 for ≥ 90 % of days for the period of ≥35 days. The end of drought is announced only if the precipitation falls".*

3.4 Possibilities of identification the agrometeorological drought in Lithuania

Soil moisture (W) is measured directly and describes the soil moisture conditions at a certain depth. In this case, a soil type, soil moisture content and a critical limit of the hazard for particular species (wilting moisture) play a vital role. Therefore, each agrometereological station, which measures soil moisture (W), requires information on the soil and wilting moisture.

Comparing the HTC values calculated for each summer day in the 2011–2013 period with the measured soil moisture W (cbar) at a depth of 20 cm it was found that the values fluctuate quite similar. Despite that, the number of dry days based on W (cbar) and HTC are different. Table 5 shows the number of dry days during the period of

June–August in Biržai and Varėna in 2011-2013. A dry day was recorded when the W (cbar) value ≥80 cbar (soil moisture is below the value of the plant wilting moisture), and the HTC value <0.5.

Table 5. The number of dry days in 2011-2013 in Biržai and Varėna, identified using different methods.

	W (cbar)	HTC	W (cbar)	HTC
Year	Biržai		Varėna	
2011	35	0	10	0
2012	2	0	1	0
2013	48	1	20	0

According to the HTC there were only a few dry days during the analyzed period in Biržai, whereas according the HTC dry days were not registered in Varėna. Meanwhile, according to direct soil moisture measurement the number of dry days appeared to be much higher.

It should be noted that some days are defined as close to optimal condition according to HTC while according to soil moisture measurements these days are described as dry. When the soil type and moisture of the plant wilting point are known the information about soil moisture W (cbar) may be a good indicator of agrometeorological drought.

Therefore information about soil moisture should be used as the main information for identifying agrometeorological droughts in Lithuania.

3.5. Identification of hydrological droughts according to SRI for 1961–2010

Analysis of hydrological droughts of 1961–2010 period, in Merkys (near Puvočiai), Jūra (near Tauragė), Šešupė (near Kudirka Naumiestis), Šventoji (near Ukmergė), showed growth of SRI values according to all time steps, i.e. runoff is increased (table 6).

Analysis of hydrological droughts in Lithuania according to ***SRI12*** calculated for September, showed that indicated droughts of hydrological year were more frequent at the beginning and end of analyzed period, and there were lower number of droughts in the middle part of the analyzed period (i.e. 1978–1991).

Table 6. Values of Mann-Kendal test statistics in river basins at different time steps of 1961-2010 period.

	SRI12	**SRI4**	**SRI3**		**SRI1**		
River (WMS)	**09**	**09**	**07**	**10**	**06**	**07**	**08**
Jūra (Tauragė)	1.04	0.97	0.33	0.31	1.66	1.75	0.68
Merkys (Puvočiai)	2.09*	2.07*	0.99	2.23*	0.90	1.31	1.36
Šešupė (Kudirkos Naumiestis)	1.64	1.02	0.48	0.96	0.00	1.45	0.71
Šventoji (Ukmergė)	1.76	2.72*	0.64	2.53*	1.28	3.11*	1.98

*statistically significant changes ($p \leq 0.5$).

According to ***SRI4*** calculated for September, there were registered from 4 (in Šventoji) to 9 (in Merkys) hydrological droughts in analyzed rivers basins.

During the analysis of recurrence of droughts in the period of 1961–2010, decrease of number of hydrological droughts since 1976 was identified as well.

Analysis of hydrological droughts during the period of 1961–2010, according to ***SRI3*** calculated for July, showed that 22 years were identified during which hydrological drought was registered at least in one of four analyzed river basins. Although only in 1971 hydrological drought was registered in all four rivers. In all other cases, hydrological droughts were registered at most in two rivers.

During 1961–2010 August–October period (SRI3 calculated for October), there were 16 years, when hydrological drought was registered at least in one of four analyzed rivers. Hydrological droughts were registered in all four (1969, 1971 and 1976) or at least three (1964 and 1968) analyzed rivers at the same time in August–October period. It is evident that most droughts were registered in the first part of analyzed period.

SRI1 was used for analysis of hydrological droughts of summer months (June, July and August). It was found that in July and August during the 1977–1992 period, hydrological droughts were not registered in any of the analyzed rivers. There were registered no one hydrological drought in river Jūra and only one in Šventoji river in August of 1977–2010.

There were registered hydrological droughts in all four or three rivers at the same time in July and August, but in June – only in one river or two rivers. This is caused by the fact, that precipitation is more significant for river runoff during July and August. River runoff in June, with some delay, still can be dependent on the spring flood and snow deposits in river basin.

It was determined, that for rivers, whose main feeding source is groundwater (for example Merkys), drought is identified even when there is very little runoff deviation (10–20 %). In rivers, whose main feeding source is rainfall (for example Jūra), drought isn't registered even after runoff decreases by two times.

The main factors that influences rivers runoff changes throughout the year are climatic factors, surface properties and river feeding type. During the warm period, one of the most significant reasons of hydrological drought is a lack of precipitation; so runoff gets lower, when precipitation deficit is higher. It is especially evident in Jūra and Šešupė, in which the runoff is more dependent on the amount of precipitation. In Merkys runoff deviations are significantly lower during the drought. Very important factor is predominant sandy soil in Merkys basin; it reduces the amount of spring flood runoff by absorbing the melting snow water, which is later returned during the warm period as base flow.

Cases, when values lower than environmental discharge, were reached

When river runoff reaches a value that is lower than the one specified environmental discharge value (Lietuvos Respublikos..., 2005) extreme hydrological phenomenon is registered.

Number of days in May–October of 1961–2010 period in all four rivers basins was calculated when the average discharge was lower than specified environmental discharge and were distinquished cases, when number of such days in one month were ≥15. Than it was checked if hydrological drought was identified according to SRI in all four time steps (i.e. SRI1, SRI3, SRI4, and SRI12). It was found that hydrological droughts are identified in short – SRI1 time step and usually in second half of warm period. (Fig. 14).

The river runoff in May is very heavily influenced by the time and size of spring flood and is much larger than in summer months, therefore during the drought registered according to SRI, it does not reach the values of environmental discharge. The same situation with June, during this month the river runoff is still affected by the spring flood. The best relation between droughts registered according to SRI1 and environmental discharge can be noted during the months of July, August and September, i.e. in second part of warm period.

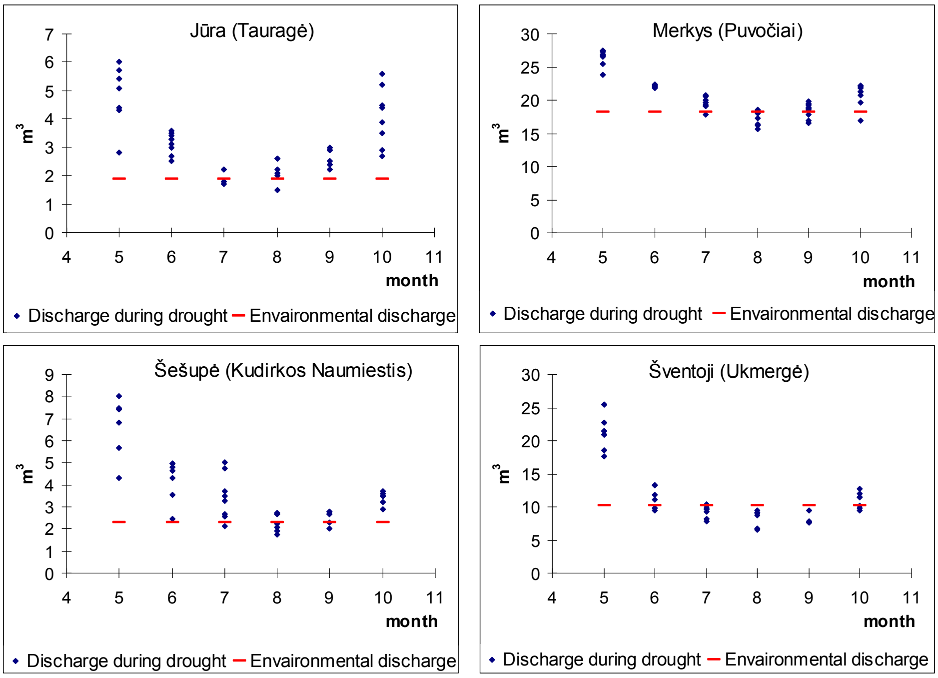

Fig. 14. The average river discharge during drought, identified according to SRI1 in 1961-2010 and environmental discharge value.

3.6. Comparison of different indices values

Comparison of SPI and HTC values

In order to compare the values of SPI and HTC indices, droughts, that were identified according to SPI and HTC values in 1891–2010 Vilnius MS, were analyzed.

There were 23 extremely dry summer months identified according to HTC value <0,5 during the 1891–2010 period. During the summer months of analyzed period, only 10 such extremely dry months according to SPI1 (SPI1≤−2) were registered, i.e. more than twice less comparing with HTC. If we change extremity criterion of SPI value from SPI<−2 to SPI<−1.5, than all extreme droughts registered according to HTC, would be also determined according to SPI1. However, during analyzed period, additional four extremely dry months would be registered according to SPI1.

The Figure 15 shows that, the relation between SPI1 and HTC values, is exponential. According to exponential relation between indices, SPI1≤−2 corresponds to 0.43 HTC; and SPI1 −1.5 corresponds to 0.58 HTC.

Currently in Lithuania one day time step is used for droughts identification according to HTC. One month time step is used for droughts identification according to

SPI1. Therefore some mismatches can occur. SPI1 cannot provide precise identification of extreme drought, determined according to HTC, if this extreme drought begins not from the beginning, but from the middle of the month.

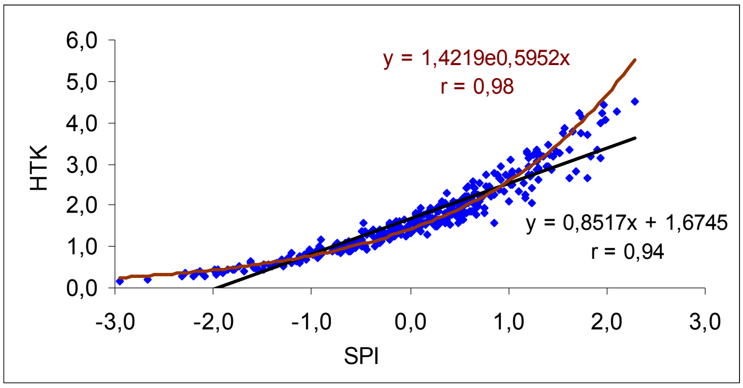

Fig. 15. The relation between HTC and SPI1 values during summer months of 1891–2010 in Vilnius.

There were identified 3 dry summers during the 1891-2010 according to HTC, during which the overall HTC of three months was <0.7; and this, according to G. T. Selianinov and S. Sapoznikov, can be evaluated as arid summer (Chirikov, 1988). According to SPI3 were also identified the same 3 summers (1914, 1964 and 1992) during which SPI3<−2.0 was calculated for August, i.e. extreme droughts were registered. The relation between SPI3 and three month HTC values must be assessed using exponential relation as well. According to exponential relation SPI3<−2 corresponds to 0.76 HTC; and SPI3 −1,5 corresponds to 0.91 HTC.

Comparison of SPI and SRI values

We compared SPI and SRI values and determined that dynamics of changes of both values were quite synchronic during the 1961–2010 period. After analyzing correlation coefficients of the same months SPI and SRI values in different time steps, it was determined that correlation largely depends on chosen time step and analyzed month.

The weakest correlation of the same months SPI and SRI is observed in those months (except according to SPI12–SRI12), when SRI value is influenced by spring flood during the analyzed period. The strongest correlation between SPI12–SRI12 values was observed in April, May, and June. River's feeding type has an effect on the correlation coefficient between SPI and SRI values. For example, in Jūra which is mostly fed by precipitation and the correlation coefficient is higher than in Merkys, which is mostly fed by groundwater.

It was found that the biggest part of hydrological droughts was formed during meteorological droughts. Due to the fact that hydrological drought can occur with a delay, we checked if the correlation between analyzed SPI and SRI values is increasing, when SRI values are shifted each one or more months forward. When the correlation coefficients of shifted time series was determined, we found that the correlation between SPI and SRI ussualy increases when SRI values are shifted by 1, 2 or 3 months forward.

3.7. Socioeconomic impact of droughts in Lithuania

Agrometeorological droughts during plant vegetation period decrease the crop yields of the agricultural plants. The biggest losses were recorded when the extreme droughts was registered: in 1992, 1994, and 2006. The droughts which were identified at the end of the vegetation period did not have a significant impact on the agricultural sector.

The number of forest fire increases due to the impact of droughts. The biggest number of forest fires was determined in 1992, 2002, and 2006. In the same year, severe droughts were registered in the large part of Lithuania. The socioeconomic impact of droughts to water transport is primarily related to river shipping. The greatest number of days when the river navigation was hindered, was recorded in the month of August and September, when the water level in rivers was the lowest.

CONCLUSIONS

1. The concept of drought is closly related to the damage caused by drought. In Lithuania droughts are most dangerous for the agricultural sector, so the concept of the drought is mostly related to the agrometeorological drought. However, during the extreme droughts registered in Lithuania, it was defined that droughts have impact to other economics and social sectors. This is why it is necessary to broaden the concept of a drought and to update the definition itself.

2. Positive and statistically significant tendencies of SPI values according different time steps in the Lithuania for the period of 1961–2010 were identified. The same tendencies were identified during the analysis of the period of 1891–2010 in Vilnius. The changes for the summer period, even positive, are not statistically significant. On the other hand, the number of short time extreme droughts during the summer period of the last two decades of the analysed period increased.

Climate humidity increase was also identified for the period of 1961-2010 for the large part of the Baltic Sea region. The biggest changes were identified at long SPI time steps. Some changes are statistically significant. Climate humidity decrease was recorded at the southern part of the Baltic Sea region.

3. Based on the CCLM regional climate output data, it is predicted that in the 21st century in Lithuania, SPI1, SPI3, and SPI24 values will increase. In the larger part of Lithuania, these changes will be statistically significant both upon A1B, and B1 climate change scenarios. During the summer time, SPI1 values on the basis of the A1B climate change scenario in all Lithuania and on the basis of the B1 scenario in the lager part of Lithuania should decrease. It means that the number of extremely dry months in the summer time may increase.

Positive annual SPI3 tendencies in the Lithuania are expected under both climate scenarios. Positive SPI3 changes in summer months are expected under B1 climate scenario in the whole territory. Meanwhile under A1B climate scenario positive SPI3 changes are expected only in the coastal area of Lithuania. Negative changes are predicted in the remaining part of the Lithuania. Positve and statistcally significant changes of SPI24 values are predicted in the whole Lithuania under B1 climate scenario and almost in whole territory under A1B climate scenario.

On the basis of both climate change scenarios it is predicted that the number and intensity of droughts in almost all Baltic Sea region will decrease. Only for the southern part of this region drought number increase is predicted.

4. According to HTC, for the period of 1961–2010, Lithuania can be characterized by the increase of the number of the extreme droughts and increase of their covered territories. The most extreme droughts were registered during the last two decades of the analysed period. For the extreme droughts, their formation and duration periods a substantial negative deviation of precipitation amount is characteristic

(by 53–88 % less than the average) and, most often, a positive deviation of air temperature (on average by 1.6 °C) from the average of 1961–2010.

Research results show that the extreme one month SPI1 value (≤−2) on average corresponds to 0.43 HTC value. That is why, according to SPI1, a smaller number of droughts is recorded than according to HTC.

5. In Lithuania, the HTC which is used for the identification of the agrometeorological droughts is not fully suitable because it disregards the information on soil moisture which should be the main criteria for the identification of the agrometeorological droughts. The use of the HTC should be discontinued or it could be still as a supplementary tool for drought identification.

6. Analysis of hydrological droughts of 1961–2010 period, in Merkys, Jūra, Šešupė, Šventoji basins, showed increase of SRI values according to all analyzed time steps, i.e. runoff is increased. According to different SRI time steps, the number of the identified hydrological droughts was bigger during the first half and the end of the analyzed period.

It was identified that the correlation coefficient between SPI and SRI values in certain cases increases by shifting the SRI values forward. It means that a hydrological drought forms after a certain period of time, i.e. during the meteorological drought or even after its end.

If the hydrological droughts are related to the environmental discharge, it is possible to make a conclusion that such cases are best identified with SRI1. The best relation between SRI1 registered droughts with the environmental discharge values can be noted during during the second part of the warm period.

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PARTICIPATION IN SCIENTIFIC CONFERENCES

International conferences:

„BALWOIS 2012“ (Ohrid, Macedonia 2012-05-28 − 2012-06-02);

„International Conference of Ecosystems (ICE) 2013“ (Tirana, Albania 2013-05-31 − 2013-06-05);

„BALTEX“ (Borgholm, Sweden 2013-06-10 − 2013-06-14);

„22nd Cartographic school: Geoinformatics and atmospheric science“ (Walbrych, Poland 2014-05-06 − 2014-05-09).

National conferences:

Jaunųjų mokslininkų konferencija *„Bioateitis: gyvybės ir geomokslų perspektyvos“* (Vilnius, 2010-12-01);

„Mokslas gamtos mokslų fakultete 7“ (Vilnius, 2012-10-05);

„Mokslas gamtos mokslų fakultete 8“ (Vilnius, 2014-10-03).

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SANTRAUKA

Darbo objektas

Sausros ir sausi laikotarpiai Lietuvoje bei Baltijos jūros regione.

Darbo tikslas

Išanalizuoti sausras ir sausus laikotarpius bei jų dinamiką, remiantis įvairiais sausrų identifikavimui skirtais indeksais.

Darbo uždaviniai

1. Apžvelgti meteorologinių, agrometeorologinių, hidrologinių ir socioekonominių sausrų sampratą bei jos raidą pasaulyje ir Lietuvoje.

2. Atlikti dažniausiai naudojamų sausros indeksų, skirtų identifikuoti skirtingo tipo sausras, lyginamąją analizę.

3. Naudojant skirtingų laiko žingsnių SPI indeksus išanalizuoti meteorologinių sausrų dinamiką 1961–2010 m. Lietuvoje, 1891–2010 m. remiantis Vilniaus MS duomenimis ir 1960–2009 m. Baltijos jūros regione.

4. Sudaryti meteorologinės sausros prognozes XXI amžiui Lietuvai ir Baltijos jūros regionui, remiantis SPI indeksu.

5. Išanalizuoti sausras 1961–2010 m. Lietuvoje, identifikuotas HTK indeksu bei įvertinti šio indekso naudojimo privalumus ir trūkumus.

6. Įvertinti duomenų apie dirvožemio drėgmę panaudojimo galimybę identifikuojant agrometeorologines sausras Lietuvoje.

7. Naudojant SRI indeksą išanalizuoti hidrologinių sausrų kartojimąsi 1961–2010 m. Lietuvoje, įvertinti jo tinkamumą hidrologinėms sausroms išskirti Lietuvoje.

8. Įvertinti sąsajas tarp sausras identifikuojančių meteorologinių ir hidrologinių indeksų.

9. Apžvelgti socioekonominės sausros poveikį įvairioms ūkio šakoms Lietuvoje.

Ginami teiginiai

1. Sausros samprata skirtingose pasaulio šalyse didžiąja dalimi yra nulemta sausrų sukeliamų padarinių pobūdžiu. Lietuvoje sausros dažniausiai sutapatinamos su

agrometeorologinėmis sausromis. Šiuo metu Lietuvoje naudojamas HTK nėra tinkamas indeksas agrometeorologinėms sausroms identifikuoti. Būtina tobulinti šio indekso skaičiavimo metodiką arba agrometeorologinėms sausroms identifikuoti naudoti kelis indeksus.

2. Lietuvos ir Baltijos jūros regione bendras SPI indeksu identifikuotų meteorologinių sausrų skaičius mažėja, tačiau trumpalaikių meteorologinių sausrų skaičius vasaros metu auga. Tikėtina, kad panašios tendencijos išliks ir XXI amžiuje.

3. HTK identifikuotos aktyviojo augalų vegetacijos laikotarpio sausros Lietuvoje tapo dažnesnės ir apima vis didesnę teritoriją.

4. SRI identifikuotų įvairios trukmės hidrologinių sausrų skaičius analizuojamų Lietuvos upių baseinuose sumažėjo. Identifikuojant hidrologines sausras SRI indeksu šiltuoju metu laikotarpiu, geriausia naudoti SRI1, SRI2 indeksus.

Darbo naujumas

Lietuvoje mokslinių tyrimų, skirtų sausroms, buvo nedaug ir beveik visi jie atlikti per pastaruosius dešimt metų. Bene svarbiausia priežastis yra ta, jog sausros ilgą laiką Lietuvai didelės grėsmės nekėlė ir susidomėjimas jomis išaugo tik praeito šimtmečio paskutinįjį dešimtmetį po Lietuvoje kilusių stichinių sausrų (1992 ir 1994 m.). Be to, Lietuvoje sausros dažniausiai siejamos tik su šiltuoju metų laikotarpiu ir sausrų daromais nuostoliais žemės ūkiui ir, kiek mažiau, miškams.

Iki šiol Lietuvoje plačiau buvo kalbama tik apie agrometeorologines sausras. Meteorologinėms, hidrologinėms ar socioekonominėms sausroms nebuvo skiriama pakankamai dėmesio. Šiame darbe pirmą kartą Lietuvoje analizuojami visi 4 sausrų tipai, išryškinami skirtumai tarp jų.

Pasaulinė meteorologijos organizacija dar 2009 m. viso pasaulio hidrometeorologijos tarnyboms rekomendavo naudoti SPI (standartizuotą kritulių indeksą), kaip universalų meteorologinės sausros indeksą. Tačiau Lietuvoje analizuojant sausras, šis indeksas kol kas plačiau naudotas nebuvo. Šiame darbe pirmą kartą išsamiai pagal SPI yra analizuojamos meteorologinės sausros Lietuvoje, sudarytos klimatinės prognozės XXI a. Lietuvai ir Baltijos jūros regionui.

Lietuvoje sausroms identifikuoti naudojamas oficialiai teisės aktais patvirtintas Selianinovo hidroterminis koeficientas (HTK), kurį rusų mokslininkas G. T.

Selianinovas pasiūlė dar 1928 m. Šiame darbe, išanalizavus sausras pagal HTK indeksą, apžvelgti šio indekso taikymo trūkumai, pateiktos rekomendacijos, kaip naudoti ir interpretuoti HTK.

Lietuvoje kol kas mažai dėmesio buvo skirta ir hidrologinėms sausroms, todėl buvo atlikta hidrologinių sausrų analizė SRI (Standartizuotu nuotėkio indeksu) kai kurių Lietuvos upių baseinuose.

Darbo aktualumas ir pritaikomumas

Aktualumas

Iki šiol Lietuvoje sausros terminas nėra aiškiai apibrėžtas ir siejamas tik su sausromis žemės ūkyje, augalų vegetacijos laikotarpiu. Šiuo metu Lietuvoje sausroms identifikuoti oficialiai naudojamas vienintelis Selianinovo hidroterminis koeficientas (HTK). Tačiau jis nėra tinkamas agrometeorologinei sausrai identifikuoti, nes nėra susietas su dirvožemio drėgme ir sausrų sukeltais padariniais. Todėl vertinant agrometeorologinę sausrą ir dėl jos sukeltų padarinių išmokamas draudimo išmokas, būtina įtraukti ir panaudoti informaciją apie dirvožemio drėgmę iš atkurto agrometeorologijos stočių tinklo. Vertinant sausras šiuo indeksu kyla ir interpretacijos problemų, todėl būtina pateikti rekomendacijas, pagal kurias visi šio indekso naudotojai vienodai interpretuotų gautus rezultatus.

Pasaulinė meteorologijos organizacija meteorologinėms sausroms identifikuoti yra rekomendavusi naudoti SPI. Norint vertinti sausras Lietuvoje šiuo indeksu, būtina jo tinkamumo ir naudojimo galimybių analizė. Naudojant SPI indeksą būtų galima lengviau integruotis ir į bendrą Europos sausrų monitoringo sistemą.

Sausra yra pavojingas meteorologinis reiškinys, galintis sukelti milžiniškų nuostolių. Šio darbo rezultatai parodė, kad nors Lietuvos teritorijos klimato drėgnumas didėja, trumpalaikių vasaros sausrų skaičius išaugo. Panašios tendencijos numatomos ir XXI a. Yra svarbu laiku identifikuoti skirtingų tipų sausras ir imtis tinkamų poveikio švelninimo bei prisitaikymo priemonių.

Tokios pat išvados pateikiamos ir Europos aplinkos agentūros (EAA) 2009 m. išleistoje atskaitoje. Joje pabrėžiama, kad nors su didžiausiomis vandens trūkumo problemomis susiduriama Pietų Europoje, vandens trūkumo problema tampa vis aktualesnė ir Šiaurės Europos šalyse. Tikėtina kad, dėl klimato kaitos sausros ateityje bus dažnesnės ir intensyvesnės, ypač vandens trūkumo problema aštrės vasaros mėnesiais (EAA, 2009). Šioje ataskaitoje taip pat pabrėžiama, kad svarbu visais lygmenimis – tiek ES, tiek nacionaliniu – vandens politiką integruoti į kitus politikos tikslus. Šiuos tikslus turės įgyvendinti ir Lietuva, o tam būtinos žinios apie sausras.

Pritaikomumas

Šis darbas gali būti naudingas edukaciniais tikslais praplečiant žinias apie sausros sampratą ir sausros sukeliamus padarinius. Darbe gauti rezultatai gali būti naudojami klimatologijos, hidrologijos, ekologijos, žemės ūkio, miškininkystės ir kitose srityse.

Darbas gali būti naudingas tobulinant kompensacijų ir draudimo išmokų dėl sausos padarinių sistemą.

Darbe pateikiama meteorologinių ir hidrologinių sausrų analizė bei meteorologinių sausrų prognozė XXI a. Lietuvai ir Baltijos jūros regionui gali būti naudinga rengiant vandens ir sausrų valdymo planus, kuriant prisitaikymo strategijas.

Atlikus sausrų analizę HTK indeksu pateikiamos rekomendacijos visiems šio indekso naudotojams. Taip pat pateikiamas naujas, patikslintas stichinės sausros apibrėžimas pagal HTK, kuris galėtų būti vartojamas vietoje dabartinio.

Atlikus sausrų analizę SPI ir gavus tyrimo rezultatus, šį sausrų vertinimo metodą galima siūlyti Lietuvos hidrometeorologijos tarnybai prie Aplinkos ministerijos kur jis galėtų būti naudojamas kaip pagrindinis ar papildomas metodas identifikuojant sausras Lietuvoje.

Gauti darbo rezultatai gali būti naudingi ir tolesniems panašaus pobūdžio tyrimams.

Rezultatų aprobavimas

Darbo rezultatų pagrindu paskelbta 10 publikacijų mokslo leidiniuose (iš jų 4 referuojamuose Thomson Reuters Web of Science duomenų bazėje. Disertacijos darbo rezultatai buvo pristatyti keturiose tarptautinėse ir trijose respublikinėse konferencijose.

Darbo metodika

Šiame darbe sausrų analizei buvo naudoti trys skirtingi sausrų identifikavimo indeksai: SPI, HTK ir SRI. Kiekvienas iš jų skirtas tam tikro tipo sausrai identifikuoti:

SPI ir HTK − meteorologinei, SRI − hidrologinei. Panaudojat SPI buvo sudaryta drėkinimo sąlygų prognozė XXI amžiuje Lietuvoje ir Baltijos jūros regione.

Nors HTK Lietuvoje naudojamas agrometeorologinei sausrai identifikuoti, jis dažniau priskiriamas prie meteorologinių sausros indeksų. Todėl, buvo įvertintos dirvožemio drėgmės panaudojimo agrometeorologinių sausrų identifikavimui galimybės.

IŠVADOS

1. Sausros sampratą didžiąją dalimi lemia sausrų sukeliami padariniai. Kadangi Lietuvoje sausros daugiausia nuostolių padaro žemės ūkio sektoriui, tai ir sausros samprata siejama su agrometeorologinėmis sausromis. Tačiau stipriausių registruotų sausrų metu Lietuvoje nustatyta, kad sausros daro poveikį daugeliui žmogaus veiklos sričių bei gamtinių sferų. Todėl būtina išplėsti sausros sampratą bei apibrėžimą.

2. Tyrimo metu nustatyta bendra statistiškai reikšminga įvairių laiko žingsnių SPI indekso reikšmių didėjimo tendencija visoje Lietuvos teritorijoje 1961–2010 m. Tokios pat tendencijos nustatytos ir analizuojant 1891–2010 m. laikotarpį Vilniuje. Pokyčiai vasaros laikotarpiu, nors ir teigiami, tačiau nėra statistiškai reikšmingi. Kita vertus, ekstremaliai sausų mėnesių skaičius vasarą pagal SPI1 per paskutinius du analizuojamo laikotarpio dešimtmečius išaugo.

Klimato drėgnumo stiprėjimas nustatytas ir 1961–2010 m. didesnėje Baltijos jūros regiono dalyje. Didžiausi pokyčiai nustatyti dideliuose SPI laiko žingsniuose. Dalis pokyčių yra statistiškai reikšmingi. Klimato drėgnumo mažėjimas fiksuojamas pietinėje Baltijos jūros regiono dalyje.

3. Remiantis CCLM regioninio klimato modelio išvesties duomenimis, prognozuojama, kad Lietuvoje XXI amžiuje SPI1, SPI3, SPI24 reikšmės didės. Didesnėje Lietuvos dalyje šie pokyčiai bus statistiškai reikšmingi tiek pagal A1B, tiek pagal B1 klimato kaitos scenarijus. Vasaros laikotarpiu SPI1 reikšmės pagal A1B klimato kaitos scenarijų visoje Lietuvoje ir pagal B1 scenarijų didesnėje dalyje Lietuvos turėtų mažėti. Tai reiškia, jog ekstremaliai sausų mėnesių skaičius vasarą gali išaugti. Pagal SPI3 visoje Lietuvoje numatomas statistiškai nereikšmingas indekso reikšmių didėjimas pagal A1B klimato kaitos scenarijų ir mažėjimas pagal B1 (pagal šį scenarijų

statistiškai reikšmingi pokyčiai numatomi Lietuvos pajūriui). SPI24 reikšmės XXI amžiuje turėtų augti.

Pagal abu klimato kaitos scenarijus prognozuojama, kad beveik visame Baltijos jūros regione sausrų skaičius ir intensyvumas XXI a. mažės, o klimato drėgnumas ir toliau didės. Tiktai pačiai pietinei regiono daliai prognozuojamas klimato drėgnumo mažėjimas bei sausrų skaičiaus didėjimas.

4. 1961–2010 metų laikotarpiu remianris HTK Lietuvos teritorijai būdingas stichinių sausrų skaičiaus bei jų išplitimo teritorijoje didėjimas vegetacijos laikotarpiu Pačios stipriausios stichinės sausros registruotos per paskutinius du analizuojamo laikotarpio dešimtmečius. Stichinėms sausroms, jų formavimosi bei vyksmo metu, būdingas didelis neigiamas kritulių kiekio nuokrypis (53–88 %) ir, dažniausiai, teigiamas oro temperatūros nuokrypis (vidutiniškai 1,6 °C) nuo 1961–2010 metų vidurkio. Tyrimo rezultatai rodo, kad ekstremalią SPI1 reikšmę (≤ -2) vidutiniškai atitinka 0,43 HTK reikšmė. Todėl pagal SPI1 fiksuojama mažiau sausrų nei pagal HTK.

5. Lietuvoje agrometeorologinėms sausroms identifikuoti naudojamas HTK nėra visiškai tinkamas, kadangi jam apskaičiuoti nenaudojama informacija apie dirvožemio drėgmę, kuri turėtų būti pagrindinis kriterijus identifikuojant agrometeorologinę sausrą. HTK indekso reiktų atsisakyti arba jis galėtų būti naudojamas, kaip papildoma priemonė sausroms išskirti.

6. Analizuojant hidrologines sausras SRI indeksu 1961–2010 m. Merkio, Minijos, Šešupės ir Šventosios baseinuose, nustatyta tiek hidrologinių metų, tiek įvairios trukmės šiltojo metų laikotarpio nuotėkio didėjimo tendencija. Remiantis įvairaus laiko žingsnio SRI indeksais, nustatytų hidrologinių sausrų skaičius buvo didesnis analizuojamo laikotarpio pirmoje pusėje ir jo pabaigoje.

7. Nustatyta, jog koreliacijos koeficientas tarp SPI ir SRI reikšmių kai kuriais atvejais išauga SRI reikšmes perstumiant į priekį. Tai reiškia, kad hidrologinė sausra susiformuoja po tam tikro laiko, t. y. jau esant ar net pasibaigus meteorologinei sausrai.

Siejant hidrologinę sausrą su gamtosauginiu debitu nustatyta, jog mažesnio nei gamtosauginis debito atvejai geriausiai identifikuojami − SRI1 indeksu. Geriausiai SRI1 indeksu registruotos sausros su gamtosauginio debito reikšmėmis siejasi šiltojo nuosėkio laikotarpio antroje pusėje.

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