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The 21st century projections of ground water level and hydrothermal conditions in Lithuanian peatbog ecosystems

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Peatlands play a very important role in the carbon sequestration process. However, human activity and ongoing global environmental change shifted peatlands from carbon sinks to source because warmer climates could accelerate the rate of production of carbon dioxide and methane from soils. The peatland ecosystems are very complex, but ground water level (GWL) and hydrothermal conditions (precipitation and evaporation) fluctuations are major drivers determining the state of the ecosystem. This research focuses on four peatbogs situated in different parts of Lithuanian: Aukšumala, Čepkeliai, Kerėplis, and Rėkyva. The future GWL tendencies are based on the relation to precipitation amount. Also, difference between precipitation and evaporation (P-E) was projected in near- (2016–2035) and long- (2081–2100) term future using four RCPs. The results revealed that the major changes in peatland ecosystems (for peat accumulation) covering the entire Lithuanian territory are predicted at the end of the 21st century. The most drastic changes in the peatlands will be related to major shifts in climate system (RCP8.5 scenario). Moreover, the major GWL and hydrothermal conditions changes are expected in the peatlands situated in the western part of Lithuania.

Keywords: ground water level, hydrothermal conditions, precipitation, evaporation, Lithuanian peatbogs, RCPs, 21st century climate projections, CLIMPEAT

INTRODUCTION

Peatlands contain large stocks of carbon (C) that are vulnerable to change through land use and climate change (IPCC, 2014). The role of peatlands in the terrestrial C cycle and by extension the contribution of these ecosystems to global climate change is complex. Carbon dioxide uptake contributes to negative radiative forcing (i. e. cooling), while CH_4 emissions contribute to positive radiative forcing (i. e. warming) (Limpens et al., 2008; Strack et al., 2008).

Anthropogenic disturbance due to raising temperature has changed peatlands from being a weak global carbon sink to a source (Frolking et al., 2011). Climate-induced changes in precipitation will probably be an important factor altering peatland vegetation in temperate and boreal regions, with decreasing wetness during the growing season generally associated with a shift from a Sphagnum dominated to vascular plant dominated vegetation type and a general decline of carbon sequestration in the long term (Limpens et al., 2008).

The change in climate and hydrology in high latitude regions could liberate large amounts of previously inactive soil carbon, especially from peatlands (BACC, 2008). Changes in temperature, water tables and discharge could affect delivery of dissolved organic carbon (DOC) to downstream ecosystems, where it exerts significant control over productivity, biogeochemical cycles (BACC, 2015). It will have negative impacts on regional CO_2 emissions and climate forcing (BACC, 2008).

If conditions are to be changed, terrestrial stored carbon in peatlands can be made available for exchange with the atmosphere (Korhola, 1994; MacDonald et al., 2006; Yu et al., 2010; Limpens et al., 2011; Gažovič et al., 2013). In general, relatively warm and dry periods generate drier conditions in the acrotelm and lowered bog-water tables, which could result in decreased peat growth and carbon net uptake (Gorham, 1991; Lafleur et al., 2003; Gažovič et al., 2013).

The peatlands are recognized to have the characteristics of self-regulating systems and the extent of regulation is a function of the peatland type and the source of water and nutrients (Frolking et al., 2009). However, climatic and anthropogenic effects on hydrological cycles in peatlands are evident. Dryer peatlands could not accumulate carbon dioxide, and changed conditions tend to release more methane into the atmosphere (Auterives et al., 2011; Mitsch, Hernandez, 2013). Increased understanding of past and ongoing peatland vegetation changes due to environmental controlled moisture variations in the acrotelm is therefore of crucial importance for the prediction of peatland development and carbon budget, even more so under changing climatic conditions (Belyea, Malmer, 2004; Edvardsson et al., 2016).

This research of ground water level (GWL) and hydrothermal conditions fluctuations in peatbogs in the 21st century is a part of **"Climate change in peatlands: Holocene record, recent trends and related impacts on biodiversity and sequestered carbon (CLIMPEAT)"** project (www.climpeat.lt). The main findings and results of the project could be found in Edvardsson et al. (2015a, b, 2016) and Kažys et al. (2015).

This study is a continuation of scientific paper "Hydrothermal effect on groundwater level fluctuations: case studies of Čepkeliai and Rėkyva peatbogs, Lithuania" written by J. Kažys, E. Rimkus, J. Taminskas, and S. Butkutė (2015) in journal *Geologija. Geografija*. The main goal of the research is to assess possible future climate conditions (2016–2035, 2081–2100) in peatlands by modelling the impacts of hydrothermal conditions on ground water level and carbon and methane sequestration until the end of the 21st century. The determined relations brings fresh and comprehensive information about possible state of peatbog ecosystems in the future (up to 2100). In addition, both research articles will contribute to the conservation and sustainable management of peatlands through a better appraisal of impacts, and/or feedback loops between pedospheric, atmospheric, and anthropogenic activities.

DATA AND METHODS

Firstly, a review of quantitative changes of groundwater level, carbon and methane sequestration in peatlands of Lithuania based on the forecasting quantitative indicators (air temperature and amount of precipitation), assessments of the current ecological status of Lithuanian peatlands, ecological modelling results from the neighbouring Lithuania countries (Estonia, Poland, Russia) has been made.

Secondly, the study was compiled using two approaches: (i) relation between GWL and the amount of precipitation and (ii) difference between the amount of precipitation and evaporation rate (P-E). General information about Lithuanian peatbogs could be found in Mierauskas et al. (2005), while for this research, four CLIMPEAT project peatbog sites (Fig. 1): Aukštumala, Čepkeliai, Kerėplis (Rieznyčia), and Rėkyva were used. Recent studies of Edvardsson et al. (2015b) revealed

Fig. 1. Peatbog research sites and nearest meteorological stations in Lithuania

that tree establishment in the research sites was likely to result from a combination of climatic and land-use changes, but changing climatic conditions over the 20th century have been shown to be the most important driver. Kažys et al. (2015) found that precipitation and hydrothermal coefficient are the most important factors determining GWL fluctuations during the warm season as well as determining the annual changes in the peatbogs. It means that a complex of hydrothermal conditions could be used for the identification of warm season GWL fluctuations along with precipitation amount.

Relation between GWL and the amount of precipitation

GWL monitoring sites have very limited data availability: 10 years (2002–2012) in Aukštumala and Čepkeliai and 12 years (2003–2014) in Rėkyva. Therefore, only tendencies of possible GWL changes in the 21st century based on relations between monthly GWL values and precipitation sums of the nearest meteorological station (MS) (Fig. 1) were used. GWLs were analysed separately for warm (April–October) and cold (November–March) seasons, because the reaction of precipitation to GWL differs between seasons, and the second reason was that datasets for the warm season are much large than for the cold season (Kažys et al., 2015).

GWL averages for the warm season (April–October) of 9 observation wells in Aukštumala and 6 observation wells in Čepkeliai and Rėkyva were used. For Čepkeliai and Rėkyva, GWL measurement is presented as the absolute GWL height (m), while for Aukštumala as a distance from pipe top to GWL (cm). Because of a different GWL calculation method, the GWL values for Aukštumala were multiplied by –1 to obtain a positive correlation sign for further interpretation. Correlation between monthly Aukštumala, Čepkeliai, and Rėkyva GWLs and different combinations of precipitation sums from Šilutė, Varėna, and Šiauliai MS were calculated: precipitation sum of the present month (season) ($\mathbf{X_0}$), precipitation sum of the past month (season) ($\mathbf{X_{-1}}$), and precipitation sum of last 3 months ($\mathbf{X_{-3}}$). The correlation coefficients were calculated and statistical significance ($\alpha = 0.05$) was evaluated. The equations of linear relation between approximated curves of variables were used for interpretation of possible GWL tendencies in the 21st century. Precipitation and temperature projections (RCP2.6, RCP4.5, RCP6.0, and RCP8.5 scenarios) for Lithuania (Keršytė et al., 2015) were used for determining the near-term (2016–2035) and long-term (2081–2100) tendencies of GWL change.

The cold season (November–March) GWL data are available only from Rėkyva peatbog, because only there automatic GWL fluctuation meters were installed in 2011. GWL reaction to precipitation depends on the distance from Lake Rėkyva (Kažys et al., 2015); therefore, GWLs were calculated for different combinations of observation wells: averaged GWL from 6 observation wells ($\mathbf{R_A}$), averaged GWL from 3 wells nearest to the lake ($\mathbf{R_N}$), and averaged GWL from 3 wells most far from the lake ($\mathbf{R_F}$). Moreover, because the variability of precipitation state (liquid, mixed, solid), snow cover and permafrost is high, relations between GWL and precipitation were not linear type in the cold season. Different combinations of precipitation and GWL were analysed: precipitation sum in November ($\mathbf{P_{11}}$), precipitation sum in winter (December–February) ($\mathbf{P_W}$), precipitation maximum within one of winter months (December–February) ($\mathbf{P_{MAX}}$), difference between yearly maximum GWL and April–May minimum GWL ($\mathbf{GWL_{MAX-MIN}}$), and difference between October and May GWL ($\mathbf{GWL_{10-5}}$). The correlation coefficients were calculated and statistical significance ($\alpha = 0.05$) was evaluated. The equations of linear relation between approximated curves of variables were used for interpretation of probable GWL tendencies in the 21st century.

Difference between amount of precipitation and evaporation rate

Carbon and methane sequestration in peatlands have primary relationship to groundwater fluctuations and the meteorological elements, i. e. air temperature and the amount of precipitation (Limpens et al., 2008). Because the data sets of GWL measurements are not long (Kažys et al., 2015), projected values of precipitation and evaporation were taken from *KNMI Explorer* database CMIP5 project (Taylor et al., 2011). According to the last IPCC report AR5, four different RCPs' (Representative Concentration Pathways) precipitation and evaporation scenarios: RCP2.6, RCP4.5, RCP6.0, and RCP8.5 were used. The scenarios were based on output data from the CMIP5 project models ensemble. The predictions of air temperature and precipitation amount for the 21st century according to four different RCPs were already made for Lithuania (Keršytė et al., 2015). The same 4 grid cells were used for calculating differences among the amount of precipitation and evaporation rate (P-E) in peatlands (Fig. 1): Aukštumala (western Lithuania), Rėkyva (northern Lithuania), Čepkeliai (southern Lithuania), and Kerėplis (eastern Lithuania). Monthly differences between the amount of precipitation and evaporation (P-E) from January to December have been calculated. The evaluation was based on the difference of P-E in 2016–2035 and in 2081–2100 compared to the 1986–2005 base period. The P-E differences are presented in mm.

Furthermore, separate absolute (mm) and relative (%) P-E changes during summer-time (as the most intensive peat growing season) and winter-time (as the largest resupplying of groundwater level) starting from 2016–2035 and from 2081–2100 compared to the past period of 1986–2005 have been assessed.

THE ROLE OF GWL ON PEAT ACCUMULATION

Emissions of CO_2, CH_4, and NO_2 gases from the peatlands depend on their degree of water absorption. It has been estimated that the average multi-annual carbon assimilation rate in peatlands of middle latitudes is 20–30 g (C) m^{-2} per year (Valatka, Oskolaitė, 2010). The annual potential net carbon sequestration rate of peat-producing wetlands in the Baltic Sea Basin has been estimated at 8–55 t(C) km^{-2} (BACC, 2008). According to Barthelmes et al. (2015), the total CO_2 emissions of all the peatlands in Lithuania equal 0.68 ($CO_{2\text{-e}}$ Mt yr^{-1}). Several studies undertaken in Lithuania have shown that current peat accumulation conditions are not exclusive and reach from 0.11 to 0.13 cm per year illustrating almost unchangeable conditions in the peatbog. There is a great probability that peat accumulation may really slow down in particular cases of major environmental changes, though peatland ecosystems should survive in changing climatic conditions (Mažeika, 2006). Natural peatlands are associated with continuous peat accumulation and absorption of CO_2 that compensate the emission of CH_4 formed by anaerobic digestion. A high level of groundwater and low surface temperatures are among the main reasons preventing peat from fast rate decomposition (van der Linden et al., 2014).As temperature strongly influences peat humidity, arid conditions will favour and generate prevailing conditions for drought tolerant plants with clearly developed root system start to grow, while moisture adapted plants may disappear (Wu, 2012; Kettridge, Waddington, 2014).

Peatland ecosystems' response to the gradual decrease of precipitation or repetitive arid summers cannot replace transforming the Sphagnum peatbog into a tree-covered peatland (Heijmans et al., 2013). The results of Lithuanian peatbogs presented by Edvardsson et al. (2015b) therefore provide valuable insights into vegetation changes in peatbogs, also with respect to bog response to ongoing and future climatic changes. The ongoing spread of trees in predominantly undisturbed peatbogs is related to warmer and/or drier climatic conditions and, to a minor degree, to land-use changes (Edvardsson et al., 2016). Increased plant biomass under the prevailing arid conditions fails to adapt to the current situation, when the system returns to normal irrigation conditions. However, 1 °C increase in temperature has already started to change from the Sphagnum-covered into the tree-covered peat-bog (Edvardsson et al., 2015b). Similar results were obtained in Poland – decrease of moisture has strongly influenced the viability of Sphagnum, but after the regeneration of the peatland its population and functions are fully restored (Gałka et al., 2014).

Groundwater fluctuations are not always directly related to climate change; eco-hydrological response of the wetlands to the conditions can lead to homeostasis demarcating the changes of the groundwater level from the environmental conditions (Swindles et al., 2012; Kettridge, Waddington, 2014). Having summarized the study on the response of the hydrological regime it was found that hydrological response in wetland ecosystems has a strong autogenous moderation of GWL responses to external drying and wetting forcings. The negative hydrological response (the average change/fluctuation of the GWL) has well exceeded the positive one (enhanced change/fluctuation of the GWL) (Waddington et al., 2014). According to peatland studies carried out in Poland, increased air temperatures and nearly the same not altered amount of precipitation will increase the evapotranspiration, which in turn diminish the groundwater level (Słowińska et al., 2012). According to the studies carried out in Estonian wetlands, deficiency of moisture is best for the fluctuations of groundwater level, which is more depending on the amount of precipitation rather than on fluctuations of air temperature, although in case of summer lack of moisture, then temperature acts as a strengthening factor (Salm et al., 2012).

However, a lot of uncertainty has remained concerning responses of CO_2 and CH_4 to the strength of the interferences, relationships between the surface of wetlands, climate, hydrology, functions and structure of the ecosystem and biogeochemical cycles of the trace gases, as well as the processes' similarities between the different types of wetlands and their geographical distribution (Limpens et al., 2008; Waddington et al., 2014).

RESULTS AND DISCUSSION

Precipitation impact on GWL changes

The GWL change reaction to precipitation amount differs from month to month (Table 1). However, some tendencies might be observed. In May, relation between GWL and precipitation is weak and statistically insignificant. Probably, this situation is a reaction of continuous impact of cold season's GWL which is higher (the same situation occurs in all peatlands). If GWL is higher, precipitation effect is neglected, also precipitation sums are not very large in May. The highest correlation coefficients appear in summer: July and August for Aukštumala and Rėkyva, while for Čepkeliai GWL reaction to precipitation is strongest in June. The next similarity is that the accumulation of precipitation effect shows off in the end of summer; meanwhile, in the beginning, the GWL changes more correlate to the present month precipitation sums (X_0) (Table 1). In August, the GWL changes depend on summer (June–August) precipitation amount (X_{-3}).

A more detailed analysis revealed that correlation between precipitation and GWL strongly depends on peat layer thickness, local topography, distance from the water bodies, etc. (Kažys et al., 2015). The strongest correlation between Čepkeliai GWL and precipitation sums occurs in observation wells with thick peat layers. This is because of water accumulation in peat processes – a thick layer of peat could retain water for a longer time than thin layers – the correlation with precipitation is stronger for thick layers. Also, the strongest correlation appears in observation wells nearest to the lake for Rėkyva peatbog. This is because of a direct influence of Lake Rėkyva: in July–August, most of precipitation is shower type. The lake accumulates precipitation therewith it regulates the GWL of the nearest observation wells in the peatbog, while the influence on the farthest observation wells is weaker. In the warm season, excess water could be stored in thicker layers of peat; therefore, GWLs in the farthest observation wells are lower than in the lake. The closer to the lake the greater effect of heavy rains is felt (Kažys et al., 2015).

Table 1. **Correlation coefficients between GWL in Aukštumala (A), Rėkyva (R) and Čepkeliai (Č) peatbogs and various combinations of precipitation sums (X_0 – present month (season), X_{-1} – past month (season), X_{-3} – last 3 months) in the nearest MS. Statistically significant (α = 0.05) coefficients are in bold**

Combination of precipitation	May	June	July	August	September	Summer	Warm season
A_0	0.00	0.32	**0.64**	0.70	0.13	**0.69**	0.51
A_{-1}	0.30	–0.10	**0.83**	**0.72**	0.30		
A_{-3}	0.51	–0.03	**0.78**	**0.92**	0.42		
R_0	0.00	0.58	0.48	0.12	–0.15	0.53	**0.62**
R_{-1}	0.15	–0.27	0.27	**0.58**	0.11		
R_{-3}	–0.22	0.44	0.37	**0.63**	0.53		
$Č_0$	0.41	**0.58**	0.14	0.16	0.16	0.32	0.44
$Č_{-1}$	0.09	0.40	0.46	0.07	0.23		
$Č_{-3}$	0.29	**0.63**	0.51	0.41	0.35		

The GWL changes depend on precipitation amount and the tendency could remain to the end of the 21st century. The annual precipitation amount could be by 1.6–4.0% higher in 2035. The most significant changes will occur in the western part of Lithuania, minor changes in the southwest. The highest growth of precipitation is projected in January–June (mostly in April) and less intense in October–December. The fall of precipitation sums could occur in July–August (mostly in July). The same tendency should hold on to the end of the century (Keršytė et al., 2015).

Precipitation impact on GWL change (in absolute values) is weakest in Aukštumala compared with Čepkeliai and Rėkyva (Fig. 2). Every extra 10 mm of precipitation could only rise GVL by 3.4 mm in summer (Fig. 2a) and by 1.2 mm in the warm season (Fig. 2b). If the same tendencies remain until the end of the 21st century, the rise of GWL in June–July and different signs of GWL change in August–September could be possible. Because the reaction of peatbogs to precipitation has some lag effect, the GWL still grows in July–August. In general, the warm season GWL could stay almost unchanged throughout the 21st century in Aukštumala, because of a different sign of tendencies during the months. A small increase of GWL could only be possible due to more heavy precipitation events during summer.

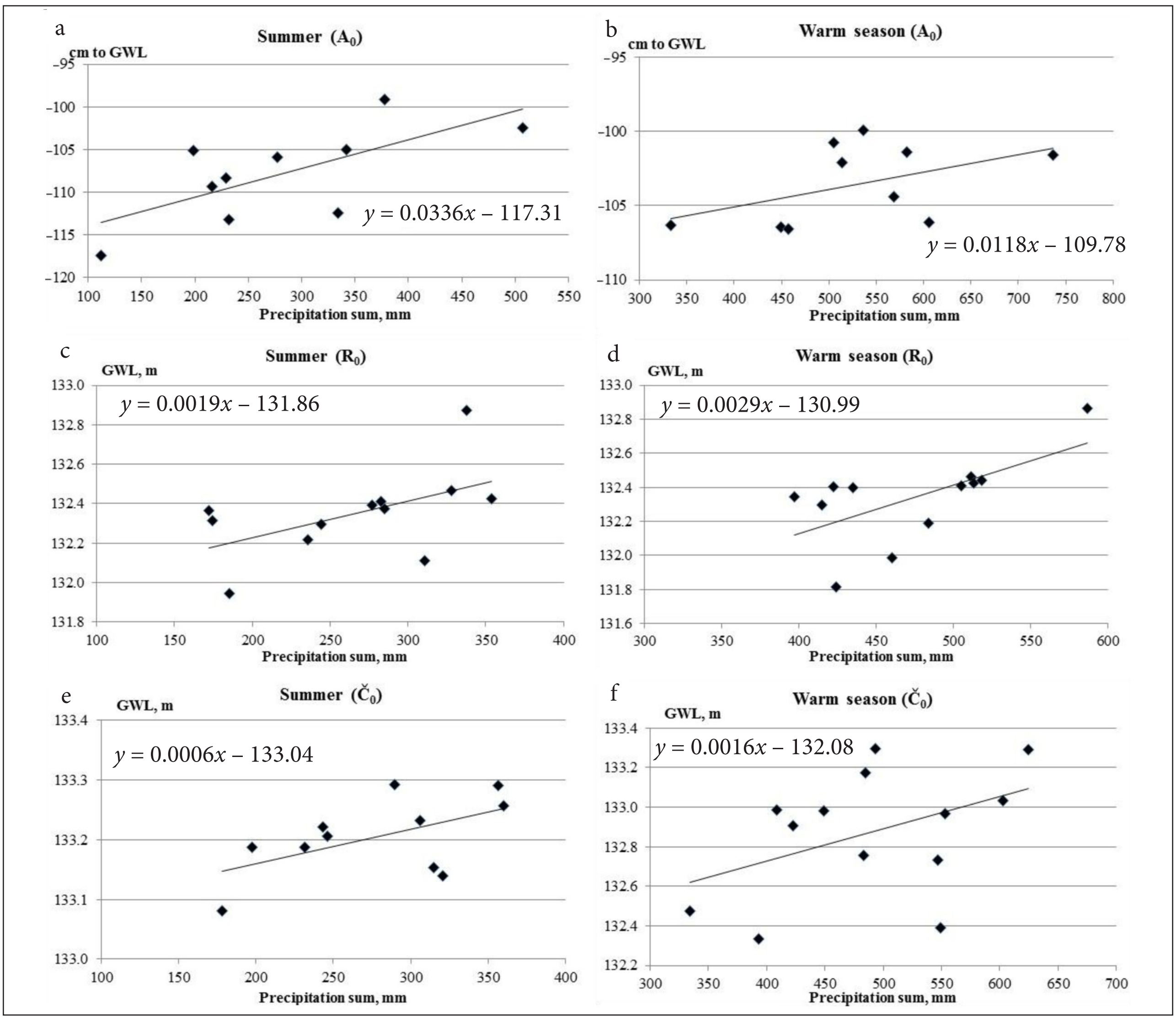

Fig. 2. The relation between precipitation sums and GWL change in: Aukštumala (A) for summer (a) and warm season (April–October) (b); Rėkyva (R) for summer (c) and warm season (April–October) (d); Čepkeliai (Č) for summer (e) and warm season (April–October) (f) with linear approximation and equation

The GWL reaction to precipitation amount is stronger in Čepkeliai: every 10 mm of precipitation brings 0.6 cm for summer (Fig. 2e) and 1.6 cm for the warm season (Fig. 2f), though correlation coefficients between precipitation sums and GWL are not statistically significant (Table 1). The GWL changes based on RCP2.6 project stable situation during the 21st century, while RCP8.5 projects increase of GWL in 2016–2035 and decrease in 2081–2100 period. It is very likely that a small increase of GWL could be evident in June–August and in summer and a negative change could occur in September. Summarizing Čepkeliai GWL changes in the 21st century, the most significant increase of GWL could be related with weak climate forcing (RCP2.6 scenario). Strong climate forcing (RCP8.5 scenario) could bring precipitation decrease on the second part of the warm season, and because of that GWL could stay almost unchanged.

In the 21st century, Rėkyva could face the most evident GWL changes compared to other peatbogs. Every extra 10 mm of precipitation could rise GWL by 1.9 cm in summer (Fig. 2c) and even more (2.9 cm) in the warm season (Fig. 2d). The more radiative forcing (RCPs) to climate systems the more negative GWL changes will occur in the 21st century. This is not applicable only for the near-future RCP2.6 scenario, which predicts decrement of the greenhouse gases effect in the second part of the century. If GWL rises almost in all cases in June, than a different sigh of changes of GWL could be present in other months (Keršytė et al., 2015). This is especially evident in July and September, and the most positive changes could occur in August. The positive precipitation changes in the first part of the warm season could bring positive effect on GWL in Rėkyva in the 21st century.

However, though the positive tendencies of summer and warm season GWL could occur in all peatbogs in the 21st century, the process intensity is not equal (Fig. 2). The most significant positive changes could take place in Rėkyva, while in Aukštumala, which is placed in the western part of Lithuania, the changes could even be negative due to higher temperatures and more intense evaporation rates. If climate forcing is weak (RCP2.6 and RCP4.5 scenarios), more positive GWL changes could occur. Due to higher precipitation sums in June and July, the GWL could have positive trends in the 21st century (Keršytė et al., 2015). The most negative changes of GWL in August–September correspond to precipitation changes under strong climate forcing (RCP6.0 and RCP8.5 scenarios) in the 21st century. Moreover, most of the warm season precipitation has convectional nature (heavy rains, showers) and the effect on GWL is transient. The recurrence of such heavy precipitation events will increase in the 21st century (Rimkus et al., 2011). In general, that small positive change of warm season GWL is not a main determining factor of projected overall GWL changes in the 21st century.

The cold season correlation coefficients between Rėkyva GWL ($\mathbf{R_A}$) and Šiauliai MS precipitation characteristics are presented in Table 2. The strongest relation occurs in the observation wells closest to Lake Rėkyva ($\mathbf{R_N}$), while in the farthest observation wells to the lake ($\mathbf{R_F}$) the relations are weaker. The similar tendencies are observed for the relations of warm season GWL. The precipitation sums of November ($\mathbf{P_{11}}$, liquid precipitation, no snow cover and permafrost) are very important to the formation of GWL maximum. Nevertheless, high water levels depend on western air masses activity and positive air temperatures, which prevails the rise of liquid and mixed precipitation (Kažys et al., 2009).

Table 2. **Cold season correlation coefficients between GWL in Rėkyva (R) and precipitation in Šiauliai MS (P). Statistically significant (α = 0.05) coefficients are in bold**

GWL	R_A		R_N		R_F	
Precipitation	$GWL_{MAX-MIN}$	GWL_{10-5}	$GWL_{MAX-MIN}$	GWL_{10-5}	$GWL_{MAX-MIN}$	GWL_{10-5}
P_{11}	**0.65**	–	**0.81**	–	0.35	–
P_w	**–0.66**	–	**–0.86**	–	–0.58	**0.81**
P_{MAX}	–	**0.53**	–	**0.69**	–	–

The linear approximation of relation between precipitation amount and GWL (Fig. 3) could be used for the prediction of possible cold season GWL changes in Rėkyva in the 21st century. If in the nearest future GWL change tendencies remain the same under all RCPs, then in the end of the century GWL change will depend on RCPs extremity (highest changes for RCP8.5, lowest for RCP2.6). Especially under RCP8.5 scenario, cold season precipitation will shift from solid state (snow) to liquid (rain). Also, the amount of winter precipitation will rise up to 20–26% in 2100 (Keršytė et al., 2015). The future changes of cold season GWL will depend, mostly, on overall water resources accumulated during the cold season ($\mathbf{GWL_{10-5}}$) (Fig. 3c, d) and, less, on monthly GWL maximums ($\mathbf{GWL_{MAX-MIN}}$) (Fig. 3a, b); i. e. the higher precipitation rates will distribute evenly throughout the season, and it will lead to the rise of the GWL. Though the precipitation sums of November ($\mathbf{P_{11}}$, liquid precipitation, no snow cover and permafrost) are very important to the formation of maximum GWL, the best illustration of GWL changes is $\mathbf{GWL_{10-5}}$ relation, i. e. the beginning and the end of high GWL period (Kažys et al., 2015). If the sum of precipitation in winter is considerably high (the amount depends on positive air temperatures and liquid precipitation prevalence), the GWL will rise a lot (Fig. 3c, d).

The possible GWL change in the end of the century could be more significant than in the near-future period; it is due to different precipitation changes in Rėkyva in the 21st century. The most positive changes of maximum precipitation amount in one of the winter months (it occurs mostly in December) ($\mathbf{P_{MAX}}$) and overall winter precipitation sums ($\mathbf{P_W}$) could lead to higher differences between October and May GWL ($\mathbf{GWL_{10-5}}$). The results show that the annual amplitude of GWL could rise, mostly, due to the growth of cold season GWLs. Even if the relation between winter precipitation sum ($\mathbf{P_W}$) and the lowest GWL (in April–May) is negative (Fig. 3b), it only proves that the highest values of GWL could be reached in April–May and more liquid precipitation could cause annual GWL growth in Rėkyva, especially under RCP8.5 scenario.

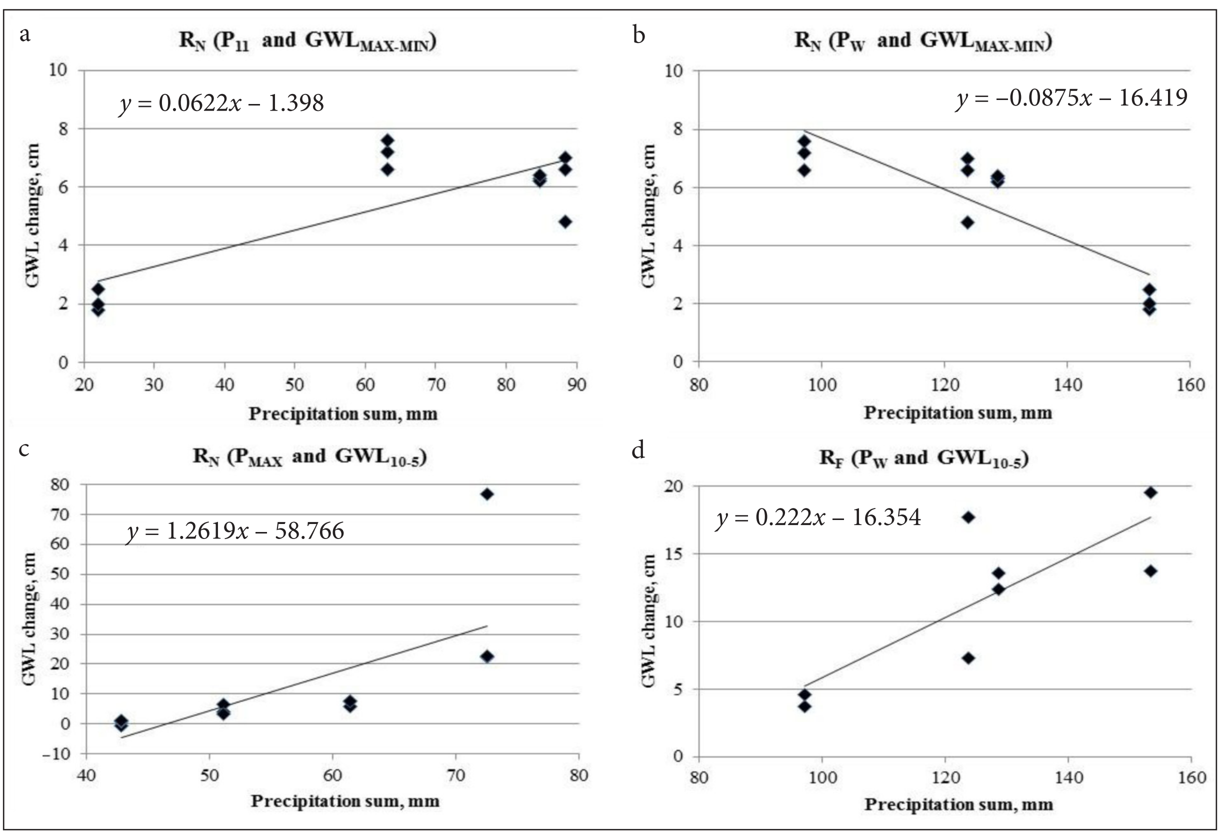

Fig. 3. The relation between different combinations of Šiauliai MS precipitation sums ($\mathbf{P_{11}}$ – sum in November, $\mathbf{P_{MAX}}$ – maximum per month, $\mathbf{P_W}$ – sum in winter) and Rėkyva GWL ($\mathbf{R_N}$ – nearest to the lake, $\mathbf{R_F}$ – far from the lake) with linear approximation and equation

Hydrothermal conditions impact on GWL

The impact of meteorological factors on the current GWL and its fluctuations in the 21st century has previously been analyzed (Edvardsson et al., 2015a; Kažys et al., 2015). However, potential peat accumulation depends not only on the amount of precipitation and on the air temperature. The GWL change in peatlands could be assumed as a difference between precipitation and evapotranspiration (Charman et al., 2009). We therefore use the difference between precipitation (P) and evaporation (E), P-E (mm). Simply speaking, evaporation describes which part of the total precipitation remains in the peatland ecosystems to supply the GWL reserves.

Most often, positive evaporation values are observed for autumn and winter months (September to April), while negative values and thereby GWL lowerings are recorded for summer months (foremost, May to August). In the 21st century, according to RCP4.5 scenario, the amount of precipitation will increase, mainly during the period of November–January (Fig. 4). At the same time, deficit will be recorded for June and July: the latter tendency is determined by the increased precipitation during the cold season, while the summer fluctuations will be determined by the increased air temperature values. Similar trends are common to all RCP groups of scenarios (Keršytė et al., 2015).

From our investigated peatlands, the lowest amplitude of difference in P-E was determined in Aukštumala (Edvardsson et al., 2015a). This is probably due to its proximity to the Baltic Sea and the specifics of the prevailing air mass circulation: higher air temperatures in winter increase the potential for evaporation of precipitation, and, vice versa, lower air temperatures in summer lead to a lower amount of precipitation due to its evaporation. Similar conditions have been

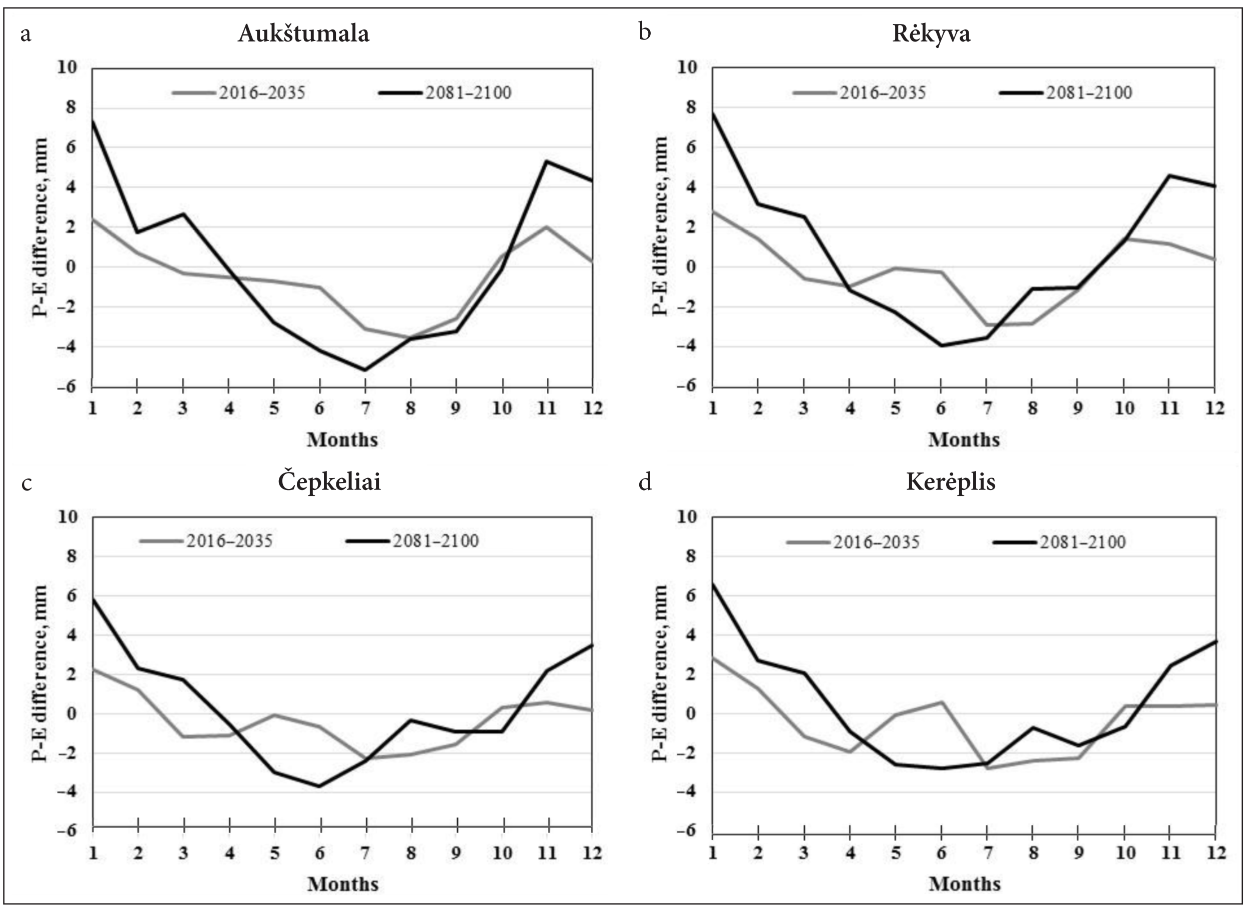

Fig. 4. Changes of the present (1986–2005) annual fluctuation of P-E difference (mm) to the nearest future (2016–2035) and the long-term perspective (2081–2100) calculated in peatlands located in different Lithuanian sites: Aukštumala (a), Rėkyva (b), Čepkeliai (c), and Kerėplis (d). Changes are based on the modelling data of the RCP4.5 group of scenarios

recorded in other peatlands: the maximum loss of precipitation potential has reached 30–35 mm in June, and the largest amount of precipitation has fallen into the peatlands in December (>60 mm). An increase of the annual amplitude of P-E has been forecasted, which might result in a higher amount of precipitation in winter and the higher deficit of precipitation in summer. The most significant changes are predicted in the western part of Lithuania (Fig. 4a) where depending on RCP group of scenarios the amplitude may fluctuate in the range of 7–28%. In other parts of Lithuania, the predicted change is believed to range between 0–14% (Fig. 4b-d).

Peat accumulation is closely linked to GWL in the peatlands (Charman et al., 2009). GWL measurements during summer (June–August) seasons and calculations of the difference of P-E determinant for our main study sites are presented in Fig. 5. The evaporated amount of precipitation is expected to increase in all the investigated raised bogs throughout the entire 21st century. Having compared different RCP groups of scenarios (the most changes in RCP8.5, the least in RCP2.6), it is obvious that major changes in the climate system could bring the increasing of negative P-E changes. The group of RCP2.6 scenarios show more significant changes forecasted during the near-term period of 2016–2035 (Fig. 5a), and for the other RCP groups, more significant changes are predicted for the end of the 21st century (Fig. 5b, d). The major changes expected in the western part of Lithuania where, depending on RCP group of scenarios and augmented values of air temperature, the amplitude may fluctuate in the range of 20–67%. Groups of RCP2.6 and RCP4.5 scenarios (Fig. 5a, b) in the southern and south--eastern parts of Lithuania are forecasted to only generate minor changes due to the increased amount of precipitation. The increased difference of P-E and deficiency of precipitation can have additional impact by the summer drought

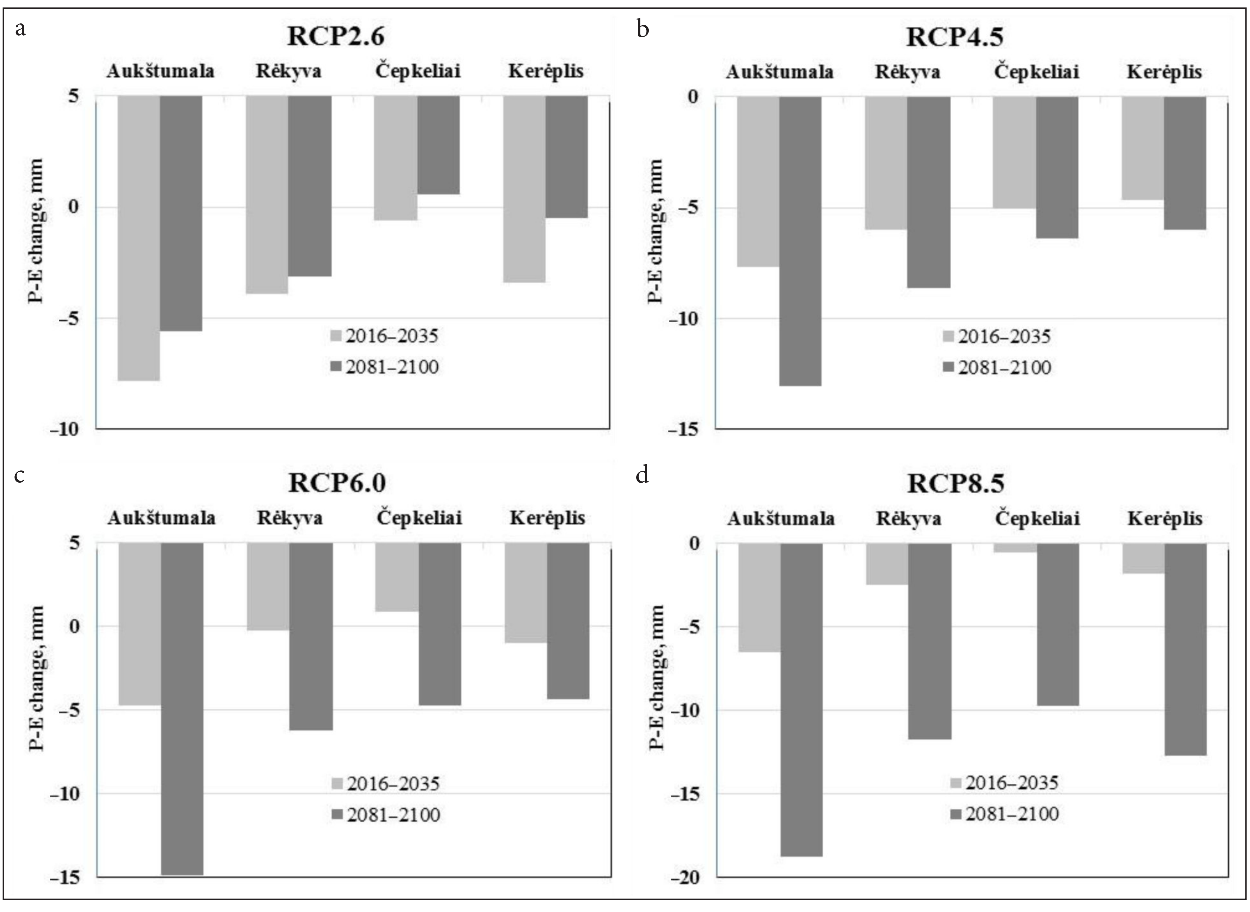

Fig. 5. Changes of P-E (mm) in the raised bogs situated in different sites of Lithuania in the near term (2016–2035) and in the long term (2081–1000) compared to the present conditions (1986–2005) during summers, based on output data from the different RCP group of scenarios: RCP2.6 (a), RCP4.5 (b), RCP6.0 (c), and RCP8.5 (d)

periods during the second half of the 21st century; however, based on the results obtained from the foreign scientific literature; the impact of droughts is even less compared to changes of the overall irrigation conditions in the peatlands of concern (Heijmans et al., 2013).

Since the major part of the precipitation evaporates in summer-time (negative P-E values), the supplement of the ground water and overall functionality of the peatlands are determined by the amount of precipitation during the cold season, especially winter (positive PE values). Although potential evaporation rate due to the increasing air temperature has a tendency to augment in the 21st century, the general amount of gross precipitation will result in additional supplementation of the groundwater level during winters (Fig. 6). Increase of P-E values are predicted as slight (1–5 mm) in the near term, while the most significant increase of those values (6–26 mm) is predicted during the period of 2081–2100. The least increment is predicted by the RCP2.6 group of scenarios (4–6%) (Fig. 6a), and the most significant by RCP8.5 group of scenarios (12–21%) (Fig. 6d).

Unlike summer seasons, absolute differences of winter P-E values among the peatlands situated in different parts of Lithuania are not considerable; this will have determination by the uniformed alike conditions for air temperature and amount of precipitation during the 21st century. The largest absolute differences are supposed to be in Rėkyva (9–26 mm), relatively in Aukštumala (6–21%).

CONCLUSIONS

1. The major ground water level (GWL) and hydrothermal conditions change in peatland ecosystems covering the entire Lithuanian territory is predicted at the end of the 21st century. At the same time, the impact will be less observable (small change

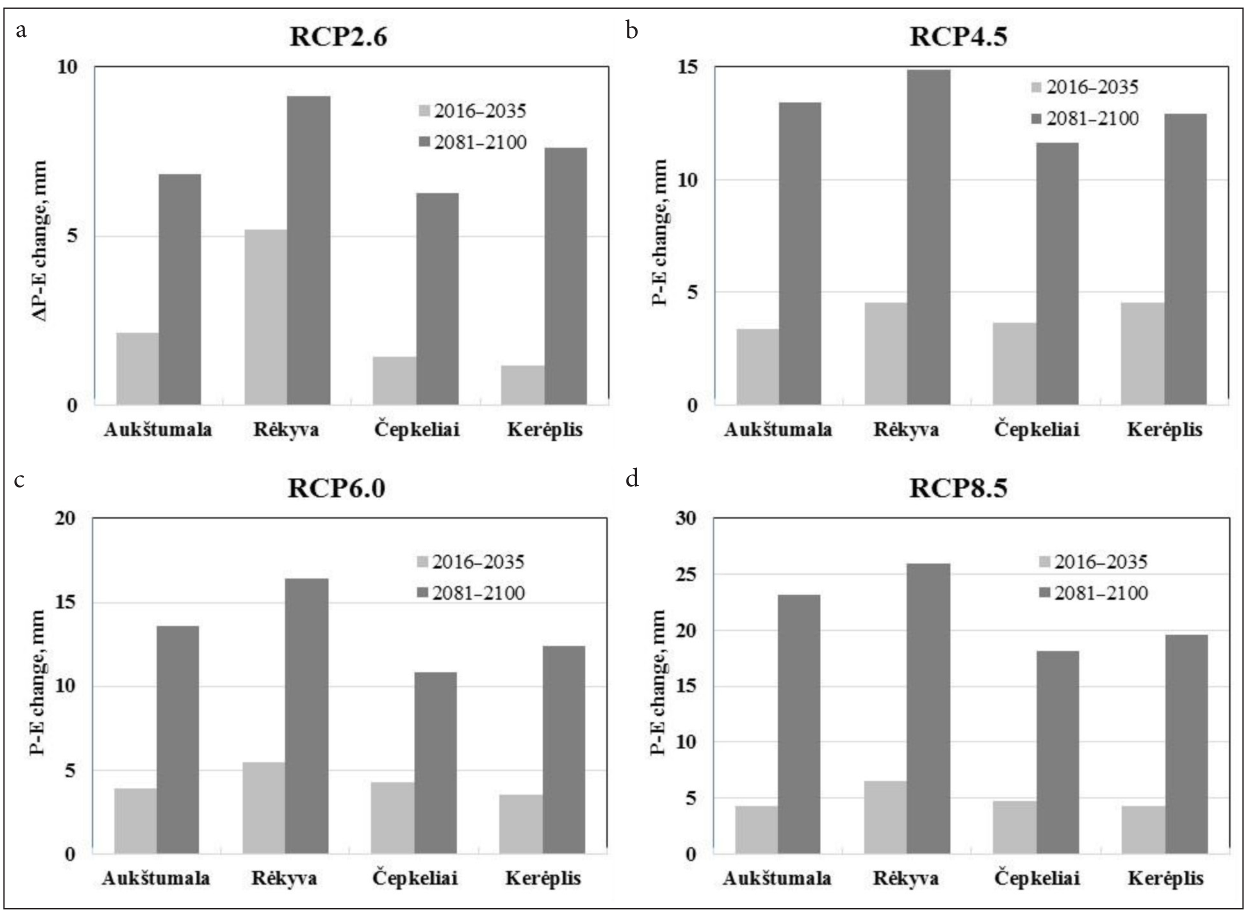

Fig. 6. Changes of P-E (mm) in the raised bogs situated in different sites of Lithuania in the near term (2016–2035) and in the long term (2081–1000) compared to the present conditions (1986–2005) during winters, based on output data from the different RCP group of scenarios: RCP2.6 (a), RCP4.5 (b), RCP6.0 (c), and RCP8.5 (d)

in hydrothermal conditions) and more regionally distinctive (western Lithuania) in the near-term period (2016–2035).

2. The strong climate forcing (RCP8.5 scenario) would cause the major GWL and hydrothermal conditions change in peatland ecosystems. In case of weak climate forcing (RCP2.6 scenario), GWL and hydrothermal conditions will remain close to the present state.

3. The major GWL and hydrothermal conditions change is expected in the peatlands situated in the western part of Lithuania and, partly, in Žemaičių Highland. For these parts of the territory, the maximum increase of air temperature (evaporation) and change in precipitation patterns have been predicted. The direct impact of the hydrothermal conditions in the eastern and southern parts of Lithuania however is believed to be less significant.

4. In warm seasons (April–October), GWL reaction to precipitation amount differs in all peatbogs: correlation between precipitation amount and GWL is higher in Aukštumala (0.69) and in Rėkyva (0.62) than in Čepkeliai (0.44). However, if the same tendencies remain in the future, that small increase of warm season GWL is not a main determining factor of projected overall GWL changes in the 21st century. The results shows that the annual amplitude of GWL could rise, mostly due to higher precipitation rates and increase of GWL in cold seasons, especially in the end of the 21st century.

5. Comparable negative summer and positive winter P-E differences have been noted in peatlands. The absolute (–4–5 mm) and relative (14–40%) deficiency of precipitation expected in the western part of Lithuania (Aukštumala) has already exceeded or is close to the increment of winter precipitation (depending on RCP group of scenarios). The absolute increase in winter precipitation generally exceeds the deficit of precipitation in summer, while relative summer-winter seasonal changes are quite similar, i. e. relative stable change differences in P-E, starting from –4.5% of that model (RCP2.6) to +7% of another model (RCP8.5). Seasonal differences are more clearly distinguished (higher deficit of precipitation amount compared to its growth) according to weaker climate forcing (RCP2.6 and RCP4.5 scenarios) compared with strong climate forcing (RCP6.0 and RCP8.5 scenario) effects.

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LIETUVOS AUKŠTAPELKIŲ EKOSISTEMŲ GRUNTINIO VANDENS LYGIO IR HIDROTERMINIŲ SĄLYGŲ PROJEKCIJOS XXI A.

Santrauka

Šis tyrimas yra 2015 m. žurnale „Geologija. Geografija“ paskelbto J. Kažio, E. Rimkaus, J. Taminsko ir S. Butkutės straipsnio „Hidroterminių sąlygų poveikis gruntinio vandens lygio pokyčiams: Čepkelių ir Rėkyvos pelkių (Lietuva) tyrimas“ tęsinys, paremtas projekto „Klimato kaita durpynuose: holoceno ženklai ir dabartinės tendencijos; įtaka bioįvairovei ir anglies deponavimui durpėse (CLIMPEAT)“ (2013–2016 m.) metu gautais tyrimų rezultatais. Tyrimo objektas – gruntinio vandene lygio (GVL) ir hidroterminių sąlygų kaita Aukštumalos, Čepkelių, Kerėplio ir Rėkyvos pelkėse (1 pav.). Pagrindinis tyrimo tikslas – įvertinti klimato kaitos poveikį aukštapelkių ekosistemoms modeliuojant ateities (2016–2035 ir 2081–2100 m.) hidrotermines sąlygas ir galimas GVL kitimo tendencijas. Gruntinio vandens lygio poveikis aukštapelkių ekosistemų raidai ir potencialiai durpių sluoksnio kaitai ateityje paremtas ryšiais tarp mėnesio (arba sezono) kritulių kiekio ir GVL bei iškirtusių kritulių ir garavimo (P-E) skirtumo, nusakančio, kuri dalis iškritusių kritulių liks pelkės ekosistemoje ir papildys GVL atsargas, analize.

Remiantis egzistuojančiais ryšiais tarp mėnesio kritulių kiekio ir GVL reikšmių, apskaičiuoti koreliacijos koeficientai tarp GVL ir kritulių kiekio šiltuoju (1 lentelė) ir šaltuoju (2 lentelė) sezonais. Pagal sudarytus šiltojo (2 pav.) ir šaltojo (3 pav.) sezonų kritulių ir GVL ryšio grafikus nustatytos galimos GVL pokyčių tendencijos artimiausioje ateityje (2016–2035) ir ilgalaikėje perspektyvoje (2081–2100). Šiltojo sezono (balandis–spalis) ryšiams nustatyti panaudoti Aukštumalos, Čepkelių ir Rėkyvos pelkių GVL ir, atitinkamai, Šilutės, Varėnos ir Šiaulių meteorologijos stočių (MS) mėnesio kritulių sumų duomenys. Šaltojo sezono (lapkritis–kovas) GVL pokyčiai įvertinti naudojant tik Rėkyvos GVL ir Šiaulių MS kritulių kiekio duomenis.

Kritulių kiekio poveikis galimiems GVL pokyčiams ateityje visose pelkėse yra skirtingas (2 pav.). XXI a. daugiausia GVL turėtų išaugti Rėkyvos pelkėje, kai vakarinėje Lietuvos dalyje esančioje Aukštumaloje GVL pokytis bus beveik nepastebimas. Galima teigti, kad didesnis vasaros kritulių kiekis ir potencialiai aukštesnis GVL nėra itin svarbus veiksnys, nulemsiantis metinius pelkių GVL pokyčius XXI a. Tuo tarpu šaltuoju metų sezonu ateityje ryškėja GVL augimo tendencijos, nes žymiai padidės šaltojo sezono GVL reikšmės (3 pav.). Aukščiausi GVL gali būti pasiekiami balandžio–gegužės mėn., o išaugęs skystos fazinės sudėties kritulių kiekis gali lemti bendrą GVL augimą Rėkyvos pelkėje. Tai ypač pastebima stipraus klimato poveikio (RCP8.5 scenarijaus) atveju.

Remiantis 4 skirtingais ateities klimato vystymosi scenarijais (RCP2.6, RCP4.5, RCP6.0 ir RCP8.5), darbe apskaičiuotos P-E skirtumo kaitos tendencijos 2016–2035 ir 2081–2100 m., palyginti su baziniu 1986–2005 m. laikotarpiu Aukštumalos, Čepkelių, Kerėplio ir Rėkyvos pelkėse. Panaudojus CMIP5 projekto RCP scenarijų išvesties duomenis apskaičiuotos minėtų laikotarpių kritulių kiekio (mm) ir garavimo (mm) reikšmės sausio–gruodžio mėnesiais. Prognozuojant XXI a. situaciją matyti, kad neišgaravusių kritulių kiekis daugiausia augs lapkričio–sausio mėn., o ryškesnis kritulių deficitas bus birželį ir liepą – tai nulems padidėjęs skystų kritulių kiekis šaltuoju metų laiku, o vasaros pokyčiams įtakos turės išaugusios oro temperatūros reikšmės (4 pav.). Šiltuoju metų sezonu, per visą XXI a., potencialiai išgaravusių kritulių kiekis augs visose aukštapelkėse (5 pav.). Didžiausi P-E pokyčiai numatomi vakarinėje Lietuvos dalyje (20–67 %), tai lems išaugusios oro temperatūros reikšmės. RCP2.6 ir RCP4.5 scenarijų grupės (5a, b pav.) pietinėje ir pietrytinėje Lietuvos dalyje prognozuoja labai nedidelius pokyčius, nulemtus išaugsiančio kritulių kiekio. Kadangi vasaros metu didesnė dalis kritulių išgaruoja (neigiamos P-E reikšmės), GVL pasipildymą ir bendrą aukštapelkių funkcionavimą lemia šaltojo sezono ir ypač žiemos kritulių kiekis (teigiamos P-E reikšmės). Nors dėl aukštesnių oro temperatūrų potencialus garingumas XXI a. išaugs, padidėsiantis bendras ir skystų kritulių kiekis lems papildomą GVL kiekį žiemą (6 pav.).

Remiantis kiekybinėmis GVL ir P-E reikšmių prognozėmis XXI a. ir kokybinėmis, moksline literatūra pagrįstomis, prielaidomis, įvertinti potencialūs anglies dvideginio ir metano deponavimo sąlygų pokyčiai Lietuvos aukštapelkėse. Nustatyta, kad didžiausi GVL ir hidroterminių sąlygų pokyčiai aukštapelkių ekosistemose visoje Lietuvoje turėtų įvykti XXI a. pabaigoje, kai artimiausioje ateityje (2016–2035) pokyčiai bus mažiau pastebimi bei labiau lokalūs (Vakarų Lietuva). Daugiausia pokyčių turėtų patirti Vakarų Lietuvos ir Žemaičių aukštumos ekosistemos, kai pietinėje ir rytinėje Lietuvos dalyse pokyčiai bus mažiau juntami. Taip pat nustatyta, kad stipresnis klimato poveikis (RCP8.5 scenarijus) turėtų labiau pakeisti GVL ir hidrotermines sąlygas aukštapelkėse, kai esant silpnesniam klimatiniam efektui (RCP2.6 scenarijus) sąlygos turėtų išlikit artimos dabartinėms.

Raktažodžiai: gruntinis vandens lygis, hidroterminės sąlygos, krituliai, garavimas, Lietuvos aukštapelkės, RCP scenarijai, XXI a. klimato prognozė, CLIMPEAT projektas