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*"Gheorghe Asachi" Technical University of Iasi, Romania*

# POTENTIAL IMPACT OF CLIMATE CHANGE ON NUTRIENT LOADS IN LITHUANIAN RIVERS

**Arvydas Povilaitis*, Elin Widén-Nilsson[2], Diana Šarauskienė[3], Jūratė Kriaučiūnienė[3], Darius Jakimavičius[3], Arūnas Bukantis[4], Justas Kažys[4], Linas Ložys[5], Vytautas Kesminas[5], Tomas Virbickas[5], Virginija Pliūraitė[5]**

[1]*Institute of Water Resources Engineering, Aleksandras Stulginskis University, Universiteto st. 10, LT-53361 Kaunas, Lithuania*
[2]*Swedish University of Agricultural Sciences, Box 7050, SE-750 07 Uppsala, Sweden*
[3]*Lithuanian Energy Institute, Breslaujos st. 3, LT-44403 Kaunas, Lithuania*
[4]*Vilnius University, Universiteto st. 3, LT-01513 Vilnius, Lithuania*
[5]*Nature Research Centre, Akademijos st. 2, LT-08412 Vilnius, Lithuania*

**Abstract**

The potential effects of climate change on nutrient (total N and total P) loads in four large-scale (A=2940–6771 $km^2$) river basins in Lithuania were analyzed. The climate impact assessment was based on an ensemble of four (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) future climate projections, representing the averaged outputs from three (GFDL-CM3, NorESM1-M and HadGEM2-ES) global climate models. For each climate projection, near-future (2016–2035) and distant-future (2081–2100) time periods were compared to the baseline period (1986–2005) to distinguish future changes.
The results have shown a decreasing trend in the annual nutrient loads in most of the studied rivers under the projected climate change. Seasonal changes in nutrient loads are also predicted with an increase occurring during the winter months and a fairly high decrease occurring in the spring and early summer months. These changes are consistent with the projected changes in the seasonal stream flow.

*Key words:* climate change, Lithuania, runoff, riverine nutrient loads

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## 1. Introduction

There is a general consensus that the Earth will be subject to warming (Bouraoui et al., 2004; Mellilo et al., 2002; Vautard et al., 2014). The Intergovernmental Panel on Climate Change (IPCC, 2013) reports that the globally averaged combined land and ocean surface temperature data show a warming of 0.85°C over the period 1880 to 2012. It is very likely that the warming will continue.

Climate changes are expected to alter the hydrological behaviour of river basins modifying the nutrient transformation and transport characteristics (Deelstra et al. 2014; Gleick, 1999; Hao et al., 2018). Changes in diffuse source pollutant loads and in nutrient cycling are among the effects to be expected (Murdoch et al., 2000).

The projections of the future climate can be estimated from simulations with global climate models (GCMs). According to Ruosteenoja et al. (2016), the sustained evolution of climate models enables the prediction of the forthcoming changes arising as a response to the increasing greenhouse gas forcing. Therefore, findings from the IPCC Fifth Assessment Report (2013) are based on a new set of scenarios called Representative Concentration Pathways (RCPs). A detailed analysis of RCP scenarios is provided in Meinshausen et al. (2011). In

* Author to whom all correspondence should be addressed: e-mail: arvydas.povilaitis@asu.lt; Phone: +370 65502300; Fax: +370 37397500

this research, the greenhouse gas concentrations for the RCPs and their extensions beyond 2100 are presented.

A number of studies based on data from the Nordic–Baltic water monitoring programmes have investigated the effects of human activity on water quality, but few have focused on the effects of climate change (Arheimer et al., 2012; Blombäck et al., 2012; Deelstra et al., 2011; Øygarden et al., 2014). The expected changes in temperature and precipitation for the Baltic Sea region are mostly derived from the IPCC Assessment Reports (Bukantis, 2007; Bukantis and Rimkus, 2005; IPCC, 2007; Jaagus, 2006; Jakimavičius and Kriaučiūnienė, 2013; Klavins and Rodinov, 2010; Kont et al., 2003; Kriaučiūnienė et al., 2008; Latkovska et al., 2012; Luomaranta et al., 2014; Øygarden et al., 2014; Rimkus et al., 2011; Ruosteenoja et al., 2015; Ruosteenoja et al., 2016; Stonevičius et al., 2018; Thodsen, 2007). All observed trends and predictions indicate that climate change is unavoidable. However, relatively little is known about the concomitant changes in water quality (Whitehead et al., 2009). Besides the climate change impacts on water availability, the consequences on water quality must be revealed (Delpla et al., 2009; Minea and Croitoru, 2016). Therefore, the purpose of the present study was to investigate the potential impact of climate change on nutrient (total nitrogen and total phosphorus) loads from four large-scale river catchments in Lithuania. The impact on nitrogen and phosphorus was chosen because they are the main nutrients responsible for the eutrophication of surface waters including the Baltic Sea. The study used four climate change projections for two future time periods.

Such predictions at the river basin scale are the first of their kind in Lithuania. The results from other studies in the Nordic–Baltic region (Blombäck et al., 2012; Øygarden et al., 2014) indicate that, for nutrients, the climate change drives changes in concentrations and loads rather than land use and management practices.

## 2. Materials and methods

### *2.1. Modelling procedures*

The climate impact assessment was based on an ensemble of four (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) future climate projections, representing averaged outputs from three (GFDL-CM3, NorESM1-M and HadGEM2-ES) global climate models (Fig.1).

The outputs were derived from the *KNMI* (Royal Netherlands Meteorological Institute) *Climate Explorer* with subsequent downscaling. The Delta method (Trzaska and Schnarr, 2014) was used for downscaling to adjust the data to local meteorological stations. This method provides an easy-to-apply way to add coarse-scale climate changes to higher-resolution observations. Finally, gridded daily values of air temperature and precipitation were obtained for the entire territory of Lithuania.

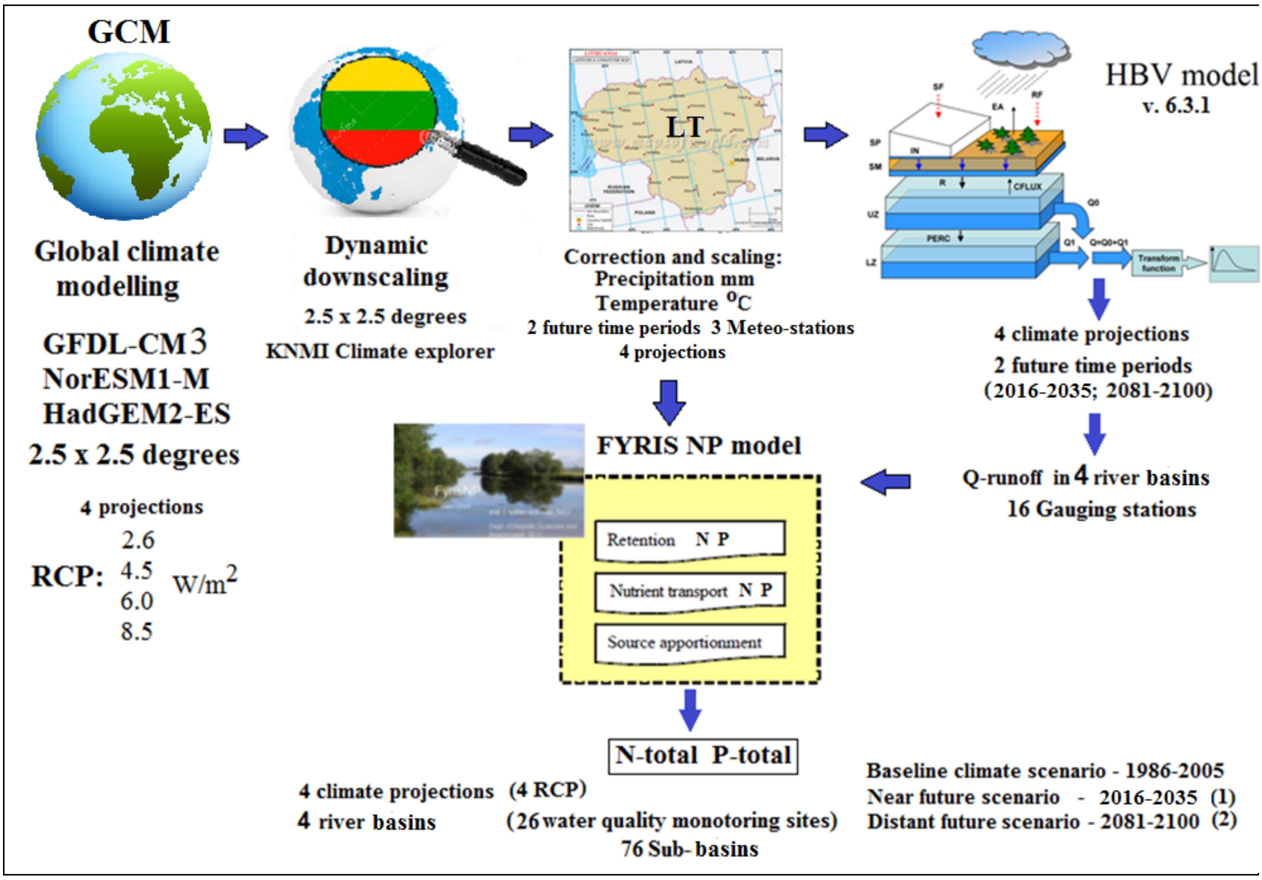



**Fig. 1.** The sequence of procedures used to assess the impact of climate change

These data were then used to drive the *Hydrologiska Byråns Vattenbalansavdelning* (HBV) hydrological model (version 6.3.1; Bergström, 1992) to assess the effects on hydrology. More details about the HBV simulations can be found in Šarauskienė et al. (2018). The results from the projected changes in air temperature and runoff were then adapted in the FyrisNP model to simulate riverine nutrient concentrations and loads. Therefore, long-term, monthly and annual outputs were analysed in the study. For each climate projection, near-future (2016–2035) and distant-future (2081–2100) periods were compared to the baseline period (1986–2005) to distinguish future changes. As in other similar studies (Arheimer et al., 2012; Ockenden et al., 2016) for the future projections, the model was run using the same land-based nutrient inputs (i.e. type-specific total nitrogen and total phosphorus leaching concentrations from different land use classes and loads from point sources) as used in the baseline period. As future changes in land use and land management practices are unknown and are determined by policy and legislation than by climate change, the obtained results illustrate how the projected air temperature and water flow changes would affect the "*business as usual*" scenario. This means that the obtained results reveal the effects of a future climate on actual land-based nutrient status. Nevertheless, it provides at least a good opportunity to predict the scope of "*what could happen…*" effects under the stated inputs with the help of the FyrisNP model.

## *2.2. FyrisNP model*

To simulate nutrient fluxes, the mass balance-based dynamic FyrisNP model (version 4.0.1) was used in this study. The model calculates nutrient loads and transport in rivers at the sub-basin level with a one-month time step resolution (Widén-Nilsson et. al., 2015). Nutrient retention is calculated as a function of lakes and stream surface area, air or water temperature and water discharge. The model is calibrated against measured concentrations of total nitrogen or total phosphorus by adjusting two empirical parameters. The two parameters are *kvs* (flow rate adjustment parameter, m $yr^{-1}$) and $c_0$ (temperature adjustment parameter, dimensionless).

When setting up the FyrisNP model for a specific river basin, relevant input data are needed (Fig. 2). The data used for calibrating and running the model can be divided into time-dependent data, e.g. time series on observed in-stream nutrient concentrations, water/air temperature, runoff and point source discharges, and time-independent data, e.g. land-use information, lake area, stream length and width, N and P leaching coefficients from soil as well as N and P wet deposition to streams and lakes.

Three meteorological stations located near Šilutė, Dotnuva and Utena towns provided data on air temperature and precipitation. The model simulated hydrological and nutrient variables for 76 sub-basins using readily available appropriate data obtained from the Lithuanian Meteorological Service, Environmental Protection Agency, Lithuanian Ministry of Agriculture, State Statistics Department and various research studies conducted (Bučienė, 2003; Povilaitis et al., 2012; Šileika et al., 2013; Šmitienė, 2008).

Type-specific concentrations of $N_{tot}$ and $P_{tot}$ leaching from arable land in sub-basins ranged from 3.4 to 11.4 mg $L^{-1}$ and from 0.060 to 0.40 mg $L^{-1}$, respectively. The leaching from pasture and meadow areas ranged from 1.1 to 2.8 mg $L^{-1}$ and from 0.050 to 0.15 mg $L^{-1}$, respectively.

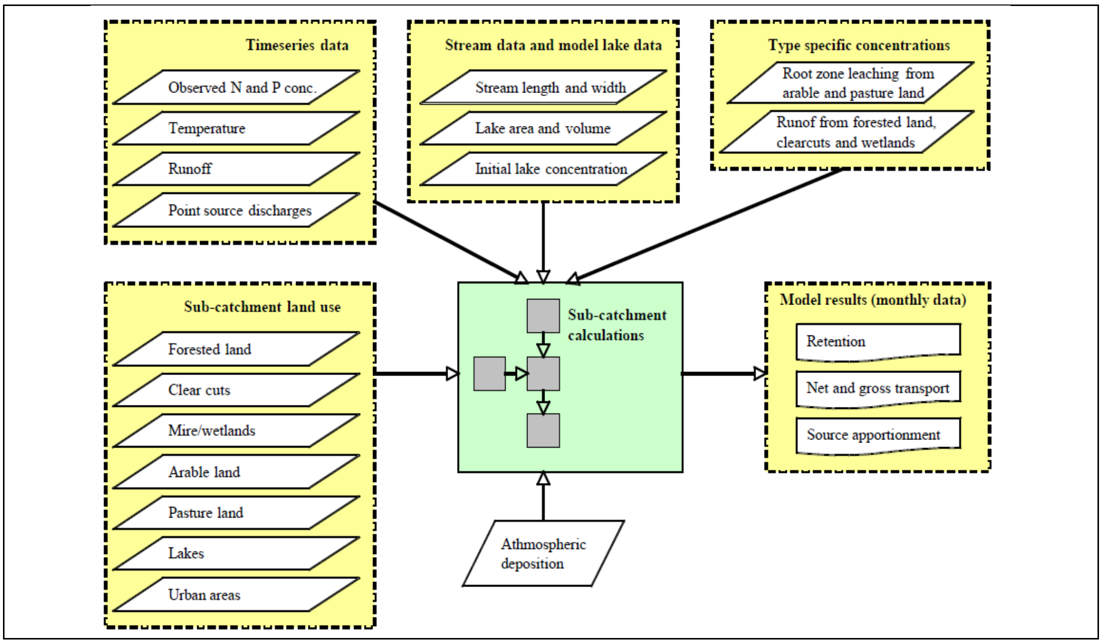



**Fig. 2.** Structure of inputs and outputs in the dynamic FyrisNP model (used with permission from Widén-Nilsson et al., 2015)

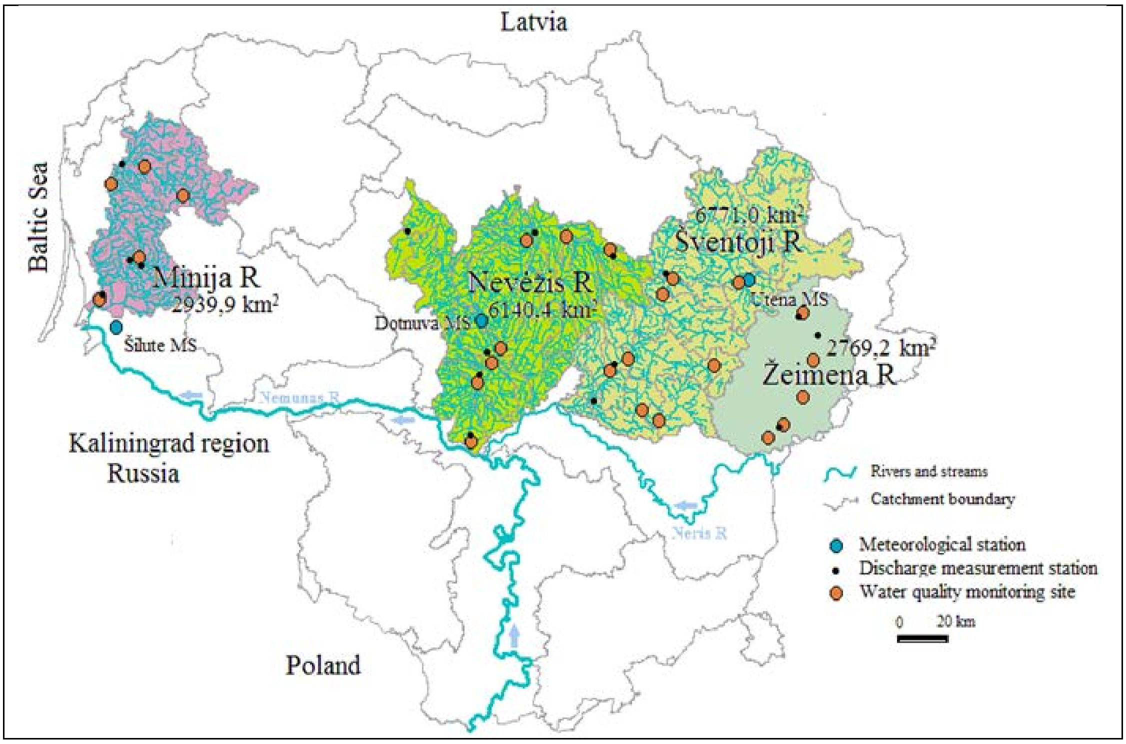



**Fig. 3.** Location map of the studied river basins along with water quantity and quality monitoring sites

**Table 1.** River basin characteristics (baseline scenario)

| ***Characteristic*** | ***Minija*** | ***Šventoji*** | ***Nevėžis*** | ***Žeimena*** |
|---|---|---|---|---|
| Total area, km$^2$ | 2939.9 | 6771.0 | 6140.4 | 2769.2 |
| Number of sub-basins | 20 | 20 | 28 | 8 |
| Mean annual temperature, °C | +9.0 | +8.1 | +8.5 | +8.1 |
| Mean annual precipitation, mm | 781 | 693 | 536 | 690 |
| Mean specific runoff, l/s km$^{-2}$ | 12.4 | 7.3 | 5.3 | 7.9 |
| Hydraulic load of surface waters, m yr$^{-1}$ | 22.3 | 6.0 | 18.7 | 3.2 |
| Land cover, % | | | | |
| Arable land | 45.9 | 46.8 | 58.8 | 20.8 |
| Forest | 39.4 | 35.9 | 30.7 | 59.6 |
| Wetlands | 1.2 | 1.6 | 0.62 | 2.3 |
| Pastures and meadows | 6.0 | 6.5 | 3.4 | 5.9 |
| Lakes and reservoirs/streams | 1.2/0.53 | 3.5/0.34 | 0.60/0.30 | 7.3/0.19 |
| Built | 4.1 | 5.4 | 3.2 | 3.6 |
| Population density, inhabitants km$^{-2}$ | 34 | 23 | 29 | 19 |
| Soils, % | | | | |
| Sand | 10.1 | 30.2 | 11.1 | 49.4 |
| Loam | 78.3 | 63.0 | 80.1 | 40.5 |
| Clay | 8.2 | 2.8 | 5.2 | 1.4 |
| Peat | 3.4 | 4.0 | 3.6 | 8.7 |
| Mean annual wet deposition | | | | |
| $N_{tot}$, kg ha$^{-1}$ | 15.1 | 20.0 | 19.0 | 21.1 |
| $P_{tot}$, kg ha$^{-1}$ | 0.8 | 1.0 | 1.3 | 1.1 |
| Flow-weighted concentrations at the lowest downstream sampling site | | | | |
| $N_{tot}$, mg L$^{-1}$ | 1.962 | 1.882 | 4.237 | 1.050 |
| $P_{tot}$, mg L$^{-1}$ | 0.090 | 0.120 | 0.146 | 0.065 |

In forest land, the leaching values varied from 0.40 to 1.4 mg L$^{-1}$ and from 0.040 to 0.080 mg L$^{-1}$, respectively. A Lithuanian GIS-based land cover map (scale 1:10,000) was used to derive the land use statistics for each of the 76 sub-basins.

The mean annual amount of precipitation and air temperature along with specific runoff and hydraulic load (defined as the annual runoff divided by the water surface area) are higher in the Minija River basin. The Minija, Šventoji and Nevėžis River basins are dominated by agricultural land, whereas Žeimena is largely forested. The Nevėžis River basin represents typical fertile lowland. By comparison, Žeimena has waters that flow across the areas that are less affected by human activity, and only the upper and lower reaches of the basin are influenced by agriculture and urbanization. Based on the data provided by the Lithuanian Environmental Protection Agency, in all four basins, discharges from municipal wastewater treatment facilities (total number = 80) are the largest point source contributors of nutrients.

### *2.3. Model calibration and evaluation*

To evaluate the goodness of fit of the simulated to observed values, two statistical parameters were applied: the Nash-Sutcliffe modelling efficiency (*E)* and Pearson's correlation coefficient (*r*). $E = 1$ implies a perfect fit where the measured and simulated series are identical, and $E = 0$ indicates that the simulation is no better than a straight line representing the average value of the observations (Moriasi et. al., 2007).

Model calibration was performed with applied Monte Carlo simulations, varying the calbration parameter $c_0$ between 0.0 and 1.0 and *kvs* between 0.0 and 30.0, and model validation was carried out for two independent data series 1996–2005 and 1986–1995, respectively, at the sites where observed nutrient data were available. The FyrisNP makes it possible to do a step-wise calibration of the parameters starting in the headwaters and continuing downstream. Therefore, different values of empirical parameters $c_0$ and *kvs* were obtained for individual sub-basins through calibration after 5000 Monte Carlo iterations. These parameters were further used to validate the model. Different modelling efficiency and correlation coefficients were achieved during these procedures (Table 2).

Despite some inaccuracies (their presence is seen from the lower values of E and r), which could be also caused by errors in measured data, the model reproduced fairly well monthly nutrient concentrations and loads. The observed values compared reasonably well with the simulated ones. This led to the conclusion that FyrisNP could be used to study nutrient fluxes in the analyzed river basins. Moreover, the obtained parameter values were assumed to be valid to run simulations under the future climate. The model was then used for numerical experimenting with changes in air temperature and runoff applying the data from the four future projections.

## 3. Results and discussion

### *3.1. Temperature, precipitation and runoff*

The next step of the analysis was to assess the impact of climate change on riverine nutrient flows. For this purpose, simulations were done using the baseline scenario set up modifying only the air temperature and runoff variables. The variables were developed from the outputs of GCMs and HBV model predictions. The projected scenarios showed an increase from 1.7°C to 3.8°C for the mean annual temperature during near future and distant future time periods, respectively. The most significant mean increase of 3.7°C and 6.0°C is predicted under RCP6.0 and RCP8.5 scenarios for the distant future period. Moreover, higher temperature rises are expected in the winter, summer and autumn months than in the spring.

It is also likely that climate change will result in higher precipitation. The mean annual precipitation amount in the studied river basins is expected to increase up to 12.4% until 2036 and up to 20.1% until 2100. The monthly amount of precipitation during different seasons is likely to increase from 7.0% to 58.9%. The most significant increase (>25%) under both scenarios is projected for February, October and December. However, 1.9–13.4% less precipitation in different river basins is predicted for January, March, September and November.

The results indicate that climate change will significantly affect the seasonal flow pattern in Lithuanian rivers (Fig. 4). It is expected that because of the accelerated snowmelt and reduced snow accumulation due to increased temperatures, the mean winter runoff (December–February) will be higher by 14.2% in the Minija River and by 6.1%, 7.9% and 8.3% in the Nevėžis, Žeimena and Šventoji Rivers, respectively.

**Table 2**. Summary* characteristics from FyrisNP model calibration and validation

| ***River basin*** | ***NWQS**** | $c_0$ | ***kvs*** | ***Calibration (1996–2005)*** | | ***Validation (1986–1995)*** | |
|---|---|---|---|---|---|---|---|
| | | | | ***E*** | ***r*** | ***E*** | ***r*** |
| $N_{tot}$ | | | | | | | |
| Nevėžis | 7 | 0.012÷0.844 | 0.957÷19.77 | 0.840÷0.922 | 0.921÷0.959 | 0.743÷0.847 | 0.924÷0.953 |
| Minija | 5 | 0.001÷0.521 | 2.699÷12.08 | 0.739÷0.863 | 0.906÷0.933 | 0.721÷0.826 | 0.881÷0.929 |
| Šventoji | 9 | 0.100÷0.995 | 3.041÷12.67 | 0.740÷0.912 | 0.847÷0.955 | 0.724÷0.909 | 0.825÷0.919 |
| Žeimena | 5 | 0.002÷0.997 | 1.219÷17.75 | 0.680÷0.753 | 0.730÷0.872 | 0.688÷0.739 | 0.735÷0.883 |
| $P_{tot}$ | | | | | | | |
| Nevėžis | 7 | 0.001÷0.699 | 0.119÷15.76 | 0.513÷0.622 | 0.514÷0.724 | 0.420÷0.701 | 0.615÷0.824 |
| Minija | 5 | 0.026÷0.903 | 0.474÷28.17 | 0.778÷0.804 | 0.884÷0.901 | 0.721÷0.773 | 0.850÷0.881 |
| Šventoji | 9 | 0.001÷0.745 | 0.842÷15.91 | 0.694÷0.762 | 0.805÷0.889 | 0.689÷0.789 | 0.831÷0.888 |
| Žeimena | 5 | 0.056÷0.649 | 0.068÷27.66 | 0.579÷0.751 | 0.702÷0.816 | 0.624÷0.680 | 0.793÷0.808 |

**with included assessment for nutrient concentrations and loads; * NWQS – number of water quality monitoring sites*

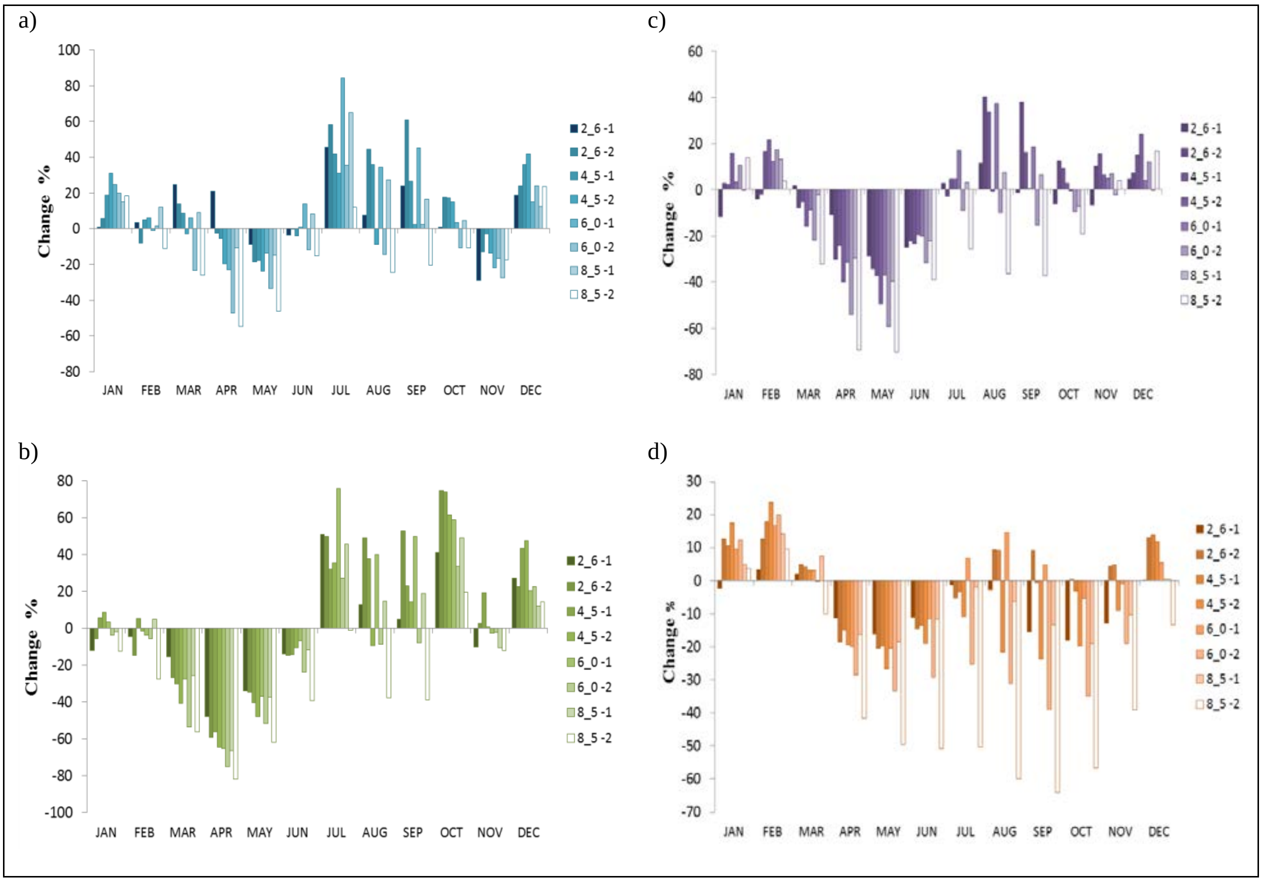



**Fig. 4.** Changes in the seasonal runoff (%) predicted by four climate projections (RCPs = 2_6; 4_5; 6_0; and 8_5) at the outlets of the Minija (a), Nevėžis (b), Šventoji (c) and Žeimena (d) rivers. Indexes "1" and "2" in the legend indicate near future (2016–2035) and distant future (2081–2100) time periods, respectively

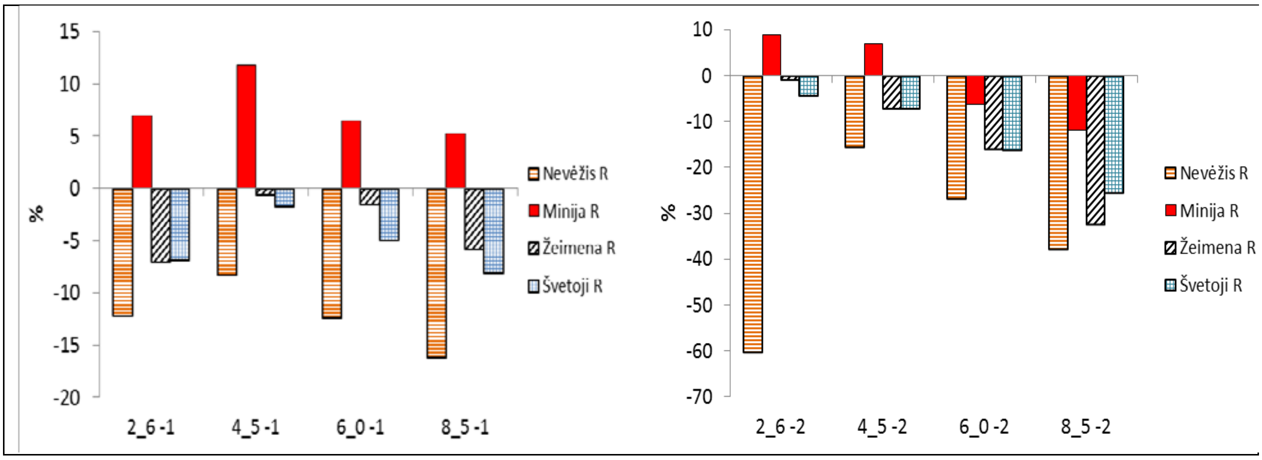



**Fig. 5.** Predicted changes in the mean annual runoff (%) under four climate projections (RCPs = 2_6; 4_5; 6_0; and 8_5) at the outlets of the studied rivers for near future (left column) and distant future (right column) time periods

Much higher (from 21.0% to 29.5% on average) runoff than the baseline scenario is predicted in the middle summer and autumn months (July–October) in the Minija and Nevėžis Rivers. Slightly lower increase (up to 2.6%) of the runoff is expected in the Šventoji River. However, for the same seasonal period, runoff reductions up to 15% are expected in the Žeimena River. The increases in the stream flow in the summer months most likely will be associated with an increased number of heavy rainstorms. Predicted runoff decreases in the Žeimena River may be associated with prevailing sandy soils and anticipated higher evapotranspiration in the basin. Lower runoff is also predicted in all the rivers during the spring and early summer months (March–June). The most pronounced decreases in the spring are expected in the Nevėžis (39.7%) and Šventoji (29.4%) Rivers. On average, up to 10% and 18% reductions in the runoff are also supposed in the Minija and Žeimena Rivers, respectively.

In general, under all projections more pronounced changes in seasonal runoff are expected for the distant future time period. In addition, changes in the mean annual runoff in all the rivers, except the Minija, for all projections show a decreasing trend (Fig. 5). The Minija River basin is a hilly area where the highest winter air temperature and the least number of days with snow cover are observed. Compare to the others, low water-permeable clay loam soils with much smaller areas of sandy aquifers prevail in this basin. As a result, less snow and rainwater accumulate there and the increased trend of future precipitation contributes to the increased annual runoff. However, due to the double rise in air temperature with a subsequent rise in evapotranspiration, the mean annual runoff under two distant future projections in the Minija River will decrease. This reveals regional peculliarities of the changes with more apparent runoff reductions in the rivers further away from the Baltic Sea to the East.

*3.2. Riverine nutrient concentrations and loads*

Stream flow changes under the projected climate scenarios will also affect riverine nutrient concentrations and loads. As shown in Fig. 6, the nutrient concentrations demonstrate pronounced monthly variability. Future changes in total nitrogen concentrations indicate a decrease in the spring and early summer months in all the rivers. The most pronounced mean decreases varying from 4.5% to 19.6% during this period are expected in the Nevėžis and Šventoji Rivers. In addition to the reductions in the spring and early summer seasons, fairly large mean decreases of up to 14.9% in $N_{tot}$ concentrations are predicted during July–November in the Šventoji and Žeimena Rivers. The winter season in these rivers is the only time period when the mean riverine $N_{tot}$ concentrations are expected to be slightly higher (from 1.0% to 4.3%) compared to the baseline scenario. In the Minija and Nevėžis Rivers, increases of up to 5.3–11.0% can be also observed during July–October. Under all projections, higher reductions in seasonal total nitrogen concentrations are predicted for the distant future time period. These changes are consistent with the changes in the seasonal flow pattern. However, higher runoff may produce higher in-stream concentrations. This presumes that the inflow of nitrogen into the rivers is dominated by non-point sources of pollution.

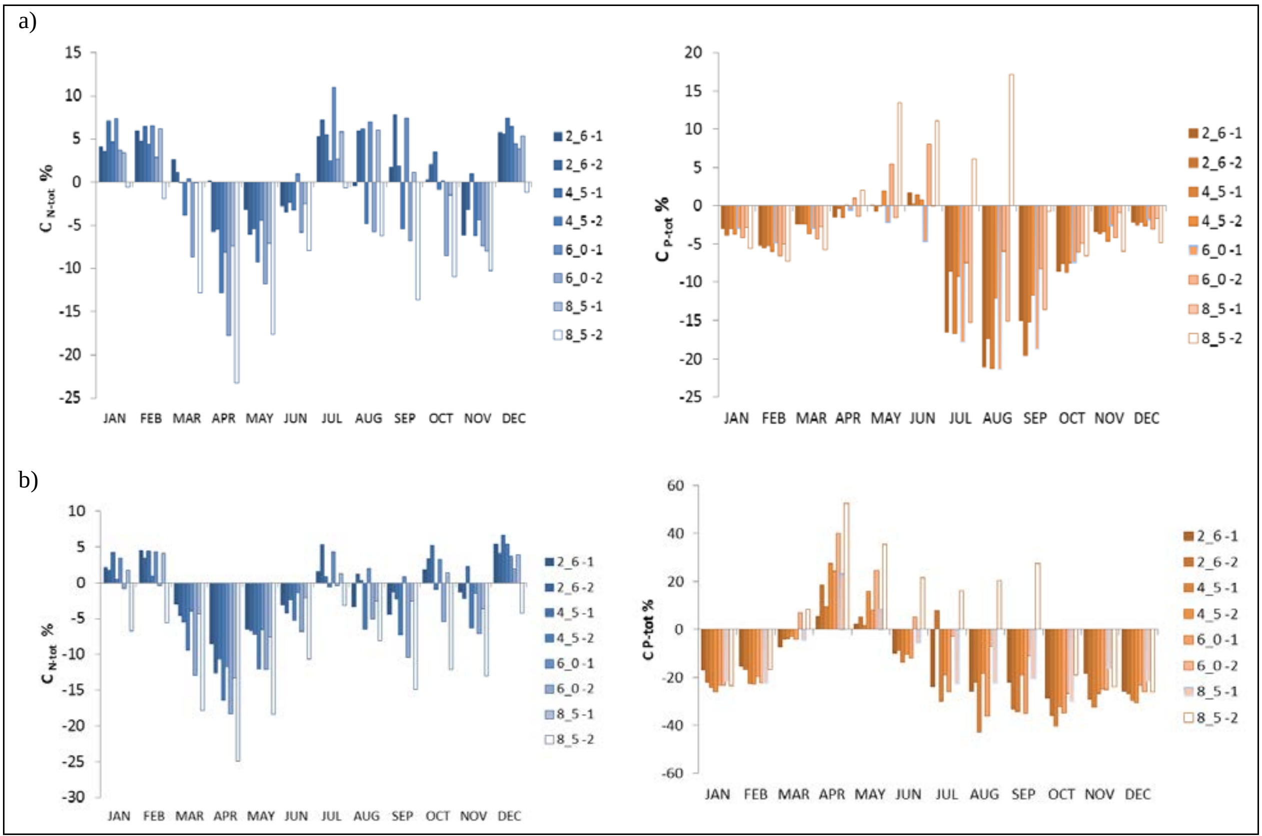
Reductions in the seasonal total phosphorus concentrations are expected (Fig. 6). All climate scenarios, except RCP6.0 and RCP8.5 for the distant future time period, show reductions in the $P_{tot}$ concentrations up to 21.4%, 42.7%, 17.4% and 6.7% in the Minija, Nevėžis, Šventoji and Žeimena Rivers, respectively. The increase in $P_{tot}$ concentrations in the spring and early summer months from 14% in the Minija River to 52% in the Nevėžis River, and a fairly high increase of up to 56% in the Žeimena River in autumn under the RCP8.5 scenario is also expected. The reasons for such changes for nitrogen also apply to the changes for phosphorus. However, they presume the opposite. It is obvious that the changes in $P_{tot}$ concentrations most often do not agree on a seasonal basis in terms of the the magnitude and the direction of changes in water flow. Consequently, these changes to some extent reveal the dilution effect of the higher water flow on point source pollutants in the rivers. The results suggest that the dominant inflow of P originates from point sources. Therefore, if relevant water management measures (e.g. achieving higher efficiency of WWTPs) are not taken, negative seasonal effects under the future climate conditions in the rivers are possible.

Climate change is also likely to change the riverine loads (Fig. 7). Although relative changes in the loads differ from one river basin to the other, both total nitrogen and total phosphorus loads are predicted to increase in the winter months by 8.1%, 10.8%, 5.5% and 7.1% for nitrogen and by 9.3%, 2.9%, 4.1% and 6.0% on average for phosphorus in the Minija, Nevėžis, Šventoji and Žeimena Rivers, respectively. These changes are consistent with the projected increases in the winter stream flow. Similar to the stream flow changes, there are also projected decreases in the spring and early summer loads. The mean decreases in the total nitrogen loads during these seasons range from 16.9% in the Minija to 45.6% in the Nevėžis, and from 16.1% in the Žeimena to 32.0% in the Šventoji Rivers for total phosphorus. Nutrient load increases in the late summer and autumn in the Minija and Nevėžis Rivers in particular are also predicted as a result of the increase in stream flow.

Under all climate projections, the changes for the distant future time period are expected to be obviously more pronounced than for the near future. The mean annual total nitrogen changes, as predicted by all climate scenarios, range from a 5.9% increase in the Minija River to a 45.1% decrease in the Nevėžis River. The mean annual total phosphorus loads vary from a 5.6% increase in the Minija River to a 32.3% decrease in the Šventoji River (Fig.8). Therefore, these predictions of nutrient loads on an annual basis indicate that future climate may reduce the transport of $N_{tot}$ and $P_{tot}$ in all the rivers, except the Minija. The main process governing the reduced loads is the reduced water flow. However, the spatial variation is large within the river basins, and thus, strong differences with an increased seasonal load can be expected. The higher precipitation and larger runoff create distinct nutrient inflow conditions in the Minija River than in the other rivers. This reveals that river basins located closer to the Baltic Sea, in contrast to the others situated further to the East, may experience higher inflows or have smaller decreases in nutrient loads in the future.

These findings are consistent with those of Arheimer et al. (2012), Chang et al. (2001), Deelstra et al. (2014), Melillo et al. (2002), Ockenden et al. (2016) and Wilby et al. (2006) reported in similar investigations intended to quantify the impacts of climate change on land-based water and nutrient loads. They point out that expected changes in the nutrient loads in river systems due to climate change are dependent on the stream flow changes for the future climate. Many research studies conducted in the Nordic–Baltic region (Arheimer et al. 2005; Bouraoui et al. 2004; Rankinen et al. 2016; Ulen and Johansson, 2009) indicate that climate change is responsible first for the reduced snow cover and increased winter runoff. Therefore, site-specific increases or decreases on an annual basis are predicted in nutrient losses with significant seasonal differences. For example, Bormann (2010) has reported that the average discharge and flow regime in German rivers has been affected by global warming. It is expected that nutrient load changes in the Elbe River due to decreasing discharge will lead to lower nutrient loads. Similarly, Panagopoulos et al. (2015) showed that due to the decreased runoff under the future climate, all agricultural management scenarios would result in reduced erosion and nutrient loadings to surface waters. Regarding agricultural management scenarios, Melillo et al. (2002) reported that soil warming due to climate change increases the availability of nutrients to plants. Because plant growth is nutrient-limited, climate change has the potential to stimulate sufficient nutrient uptake and storage in plants to compensate for the nutrient losses from the soil. However, other research studies have correlated (Bouraoui et al., 2004; Park et al., 2010) an increase in surface water flow with a subsequent increase in riverine nutrient loads. Although the reported findings from the conducted experiments differ, it is obvious that the changes in stream flow are a key factor controlling riverine nutrient concentrations and loads.

The applied FyrisNP model clearly has many simplifications aimed to reflect the complex interactions taking place in river basins. Based on the results from this study, it might be useful to change some of the parameters that were held constant during the future climate scenario simulations. When projecting future changes in nutrient concentrations and loads, only the air temperature and stream flow inputs were allowed to change. However, because climate change may also induce changes in land cover, it may be appropriate to examine such changes in the model. Similarly, it would be useful to examine the effects of changing land management practices and land-based nutrient inputs (i.e. changes in fertilizer application timing and rate and loading from point sources) along with the climate change effect. These practices could also affect the runoff volume and associated nutrient loads. Therefore, the interactions of climate change, land use management and water quality will need further investigation by applying more sophisticated process-oriented dynamic models (e.g. SWAT, BASINS, EPIC, WASP). These models allow forecasting and a better understanding of water-related processes (Arnold and Fohrer, 2005; Kiesel et al., 2010; Wang et al., 2013), but they require a sizeable amount of detailed information on river catchments (i.e. extended spatial data on site-specific soil and plant parameters and management practices), which is not always available. Nevertheless, the obtained results from this study can serve as an indication of possible risks and benefit as a relevant prerequisite for mitigation and adaptation measures to be taken.



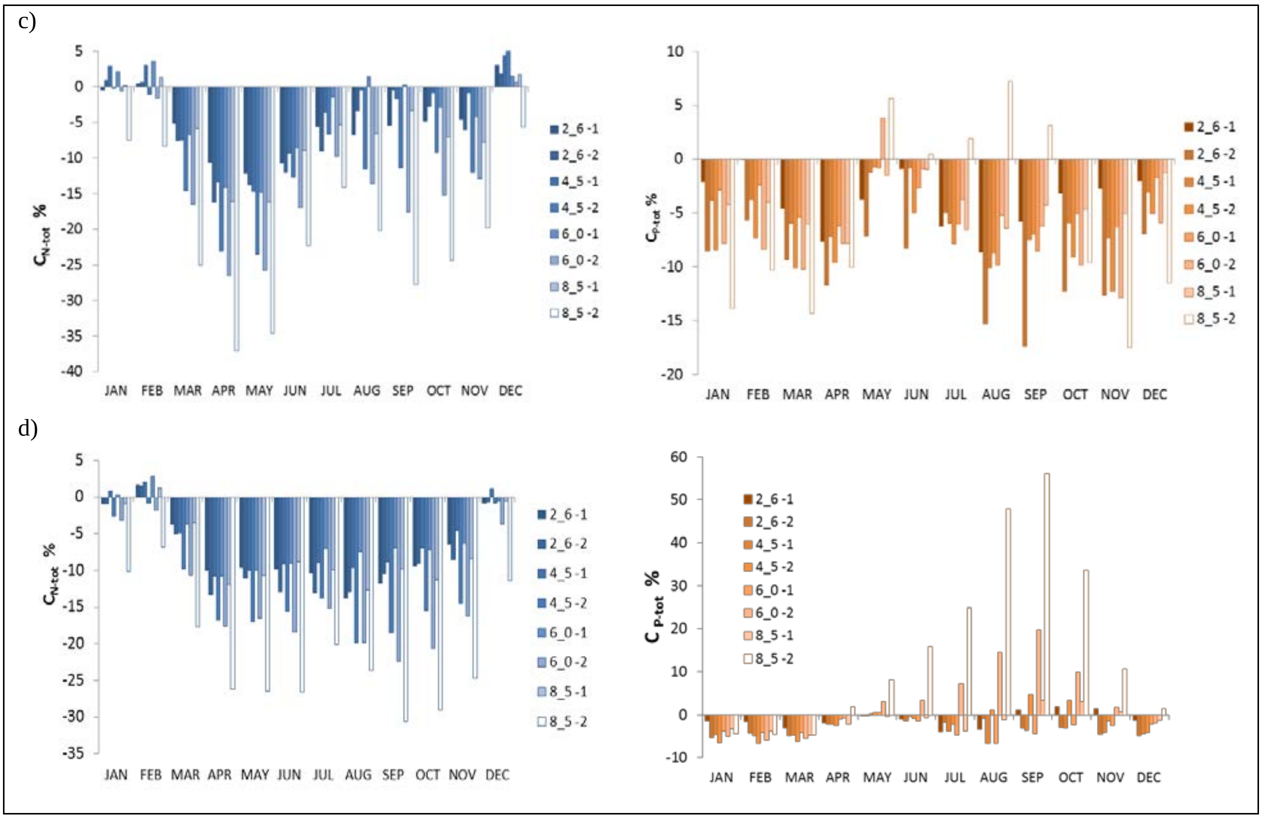
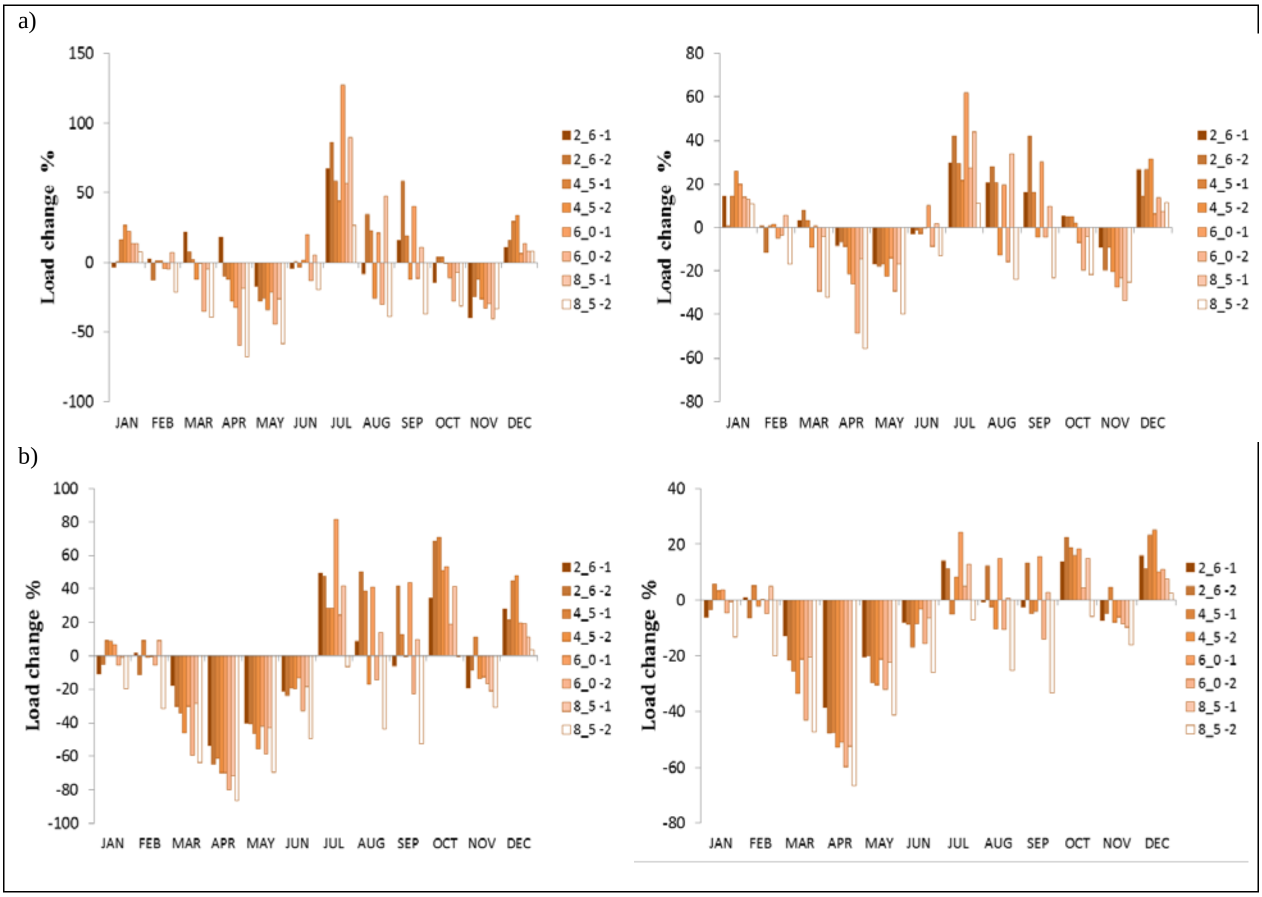



**Fig. 6.** Changes in the seasonal concentrations (%) of total nitrogen (left column) and total phosphorus (right column) at the outlets of the Minija (a), Nevėžis (b), Šventoji (c) and Žeimena (d) Rivers. Indexes "1" and "2" in the legend indicate near future (2016–2035) and distant future (2081–2100) time periods, respectively



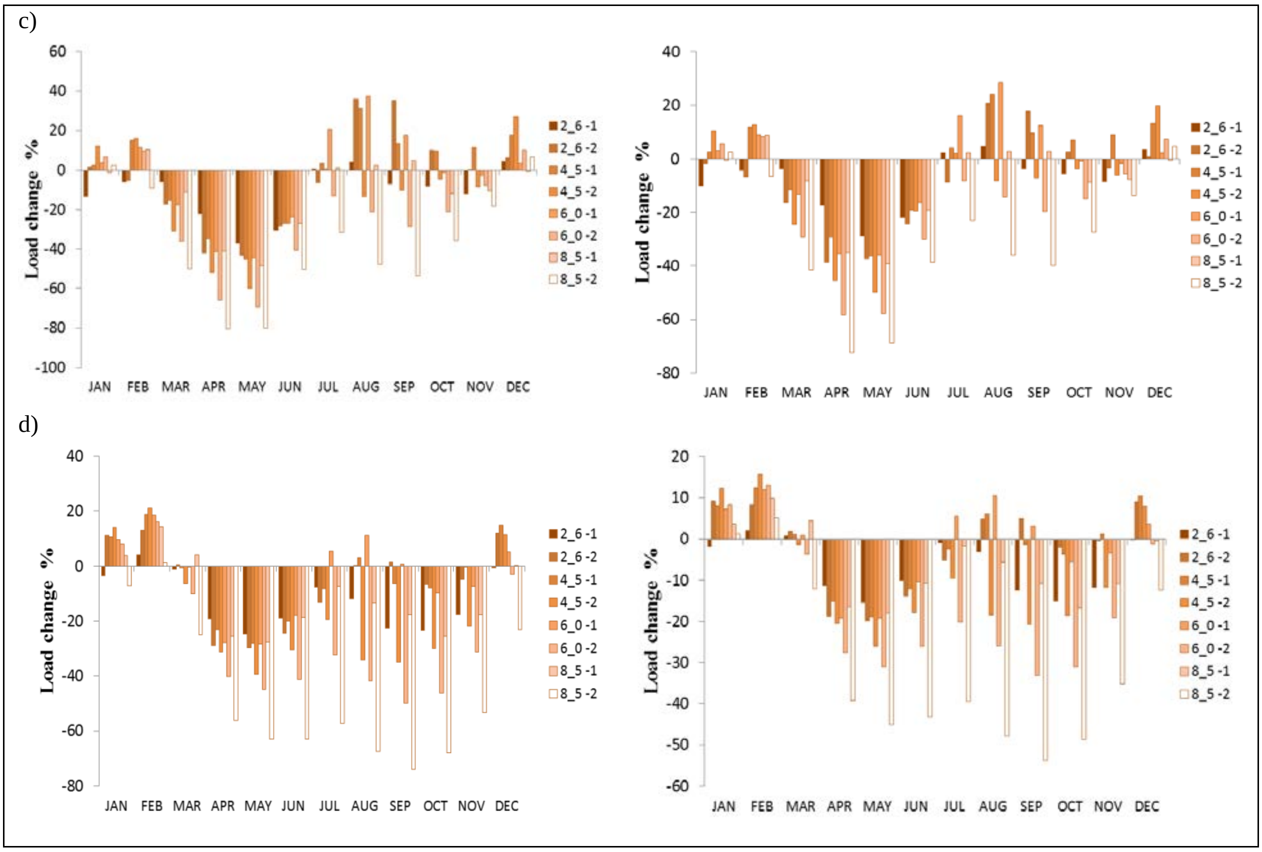



**Fig. 7.** Changes in the seasonal riverine loads (%) of total nitrogen (left column) and total phosphorus (right column) at the outlets of the Minija (a), Nevėžis (b), Šventoji (c) and Žeimena (d) Rivers. Indexes "1" and "2" in the legend indicate near future (2016–2035) and distant future (2081–2100) time periods, respectively

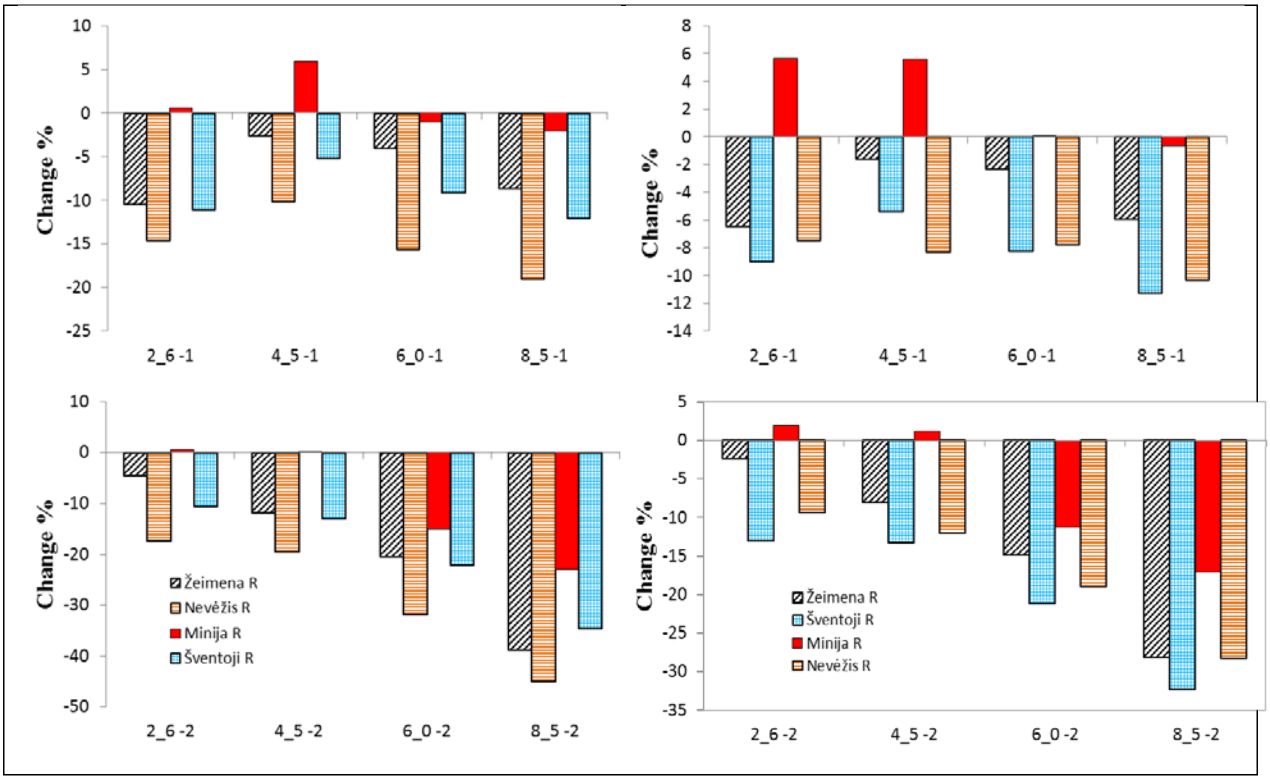



**Fig. 8.** Changes in the mean annual load (%) of total nitrogen (left column) and total phosphorus (right column) at the outlets of the studied rivers under four climate change scenarios (RCPs = 2_6; 4_5; 6_0 and 8_5) for the near future (index "1") and distant future (index "2") time periods

## 4. Conclusions

The results indicate a decreasing trend in the stream flow and nutrient loads in most of the studied Lithuanian rivers under the projected climate change. The mean annual stream flow revealed regional peculliarities of the changes with more apparent runoff reductions in the rivers further away from the Baltic Sea.

Under all projections, more pronounced reductions in the seasonal flow are expected for the future 2081–2100 time period. Seasonal changes in the nutrient loads are also expected, with an increase occurring during the winter months and a fairly high decrease occurring in the spring and early summer months. These changes are consistent with the projected changes in the stream flow. Changes in the timing and the magnitude of the stream flow are highly associated with nutrient loads.

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