TRENDS IN RIVER RUNOFF IN LATVIA FOR THE PERIOD 1951–2020

LATVIJAS UPJU NOTECES ILGTERMIŅA TENDENCES LAIKA POSMĀ NO 1951. LĪDZ 2020. GADAM

Elga Apsite, Agrita Briede
University of Latvia, Department of Geography
elga.apsite@lu.lv

Abstract
A time series of monthly, seasonal and annual mean specific runoff of rivers in Latvia are analysed in order to detect trends for the period 1951–2020. Trend analysis is performed by applying the Mann-Kendall test and the trend slope is calculated using Sen's method. There were significant seasonal changes in the time series of specific runoff measured at 32 stations during the study period. In all hydrological regions, the trend values obtained for the winter season are statistically significant, but they are relatively weaker in the Eastern region. At the same time, river runoff in April and May has notably decreased, indicating a shift of the runoff maximum to an earlier time. Long-term changes in specific runoff are statistically significant in April in all hydrological regions, and only in May for the Eastern region. Generally, statistically insignificant trends in specific runoff are observed for the summer and autumn months. Annual mean specific runoff has not revealed any strong trends in spite of the increased precipitation and temperature. Clear seasonal changes have been found in several earlier studies in the Baltic countries, and they are confirmed by the current one.
Keywords: *runoff of river, climate changes, Latvia*

Introduction

The Baltic Sea basin is among the most sensitive regions in the world to global warming, which was stated in the first BACC (2008) assessment and is still valid in the current situation (Meier et al., 2022). This has encouraged the development of many studies of the warming climate and its impact upon hydrological processes at various spatial and temporal scales. The highest number of studies are summarised in the assessment of BACC Team (2008; 2015) and by Meier et al. (2022), which also includes the Baltic countries. The authors of these studies found that increasing trends in river runoff were characteristic of the winter season during the 20th century (Jaagus et al., 2017) and the beginning of 21th century. By contrast, the spring season is characterised by a decrease in runoff. By applying different hydrological models, changes in river runoff in this region were modelled for the case of continuous climate warming. The results indicated continuous increase in runoff in winter and decrease in spring, which could lead to drought and flood conditions in different seasons at the end of this century.

Long-term fluctuations in climatic parameters are reflected in the dynamics of river runoff that has a relatively short residence time (Jaagus et al., 2017). River runoff in Latvia is characterised by significant seasonal and interannual variability. It is mostly caused by precipitation variations and snow conditions during winter and the period of melting in spring. The runoff regime is also affected by physiographical conditions, including hydrographical and hydrogeological ones, where relatively large differences can be found among different rivers' catchment areas in Latvia. Long-term changes and variability in river discharge in Latvia has been analysed by many authors within the context of the Baltic countries (Reihan et al., 2007; Kļavinš et al., 2009; Reihan et al., 2012; Kriaučiūniene et al., 2012; Sarauskiene et al., 2015) and within the context of a single country (e.g. Kļaviņš & Rodinovs, 2008). One recent study was conducted by Apsīte et al. (2013), during which two periods of study (1951–2009 and 1881–2009) were analysed. The study revealed that a long-term trend analysis of two periods of study for the same river and hydrological station mostly indicated the same significant changes in the monthly, seasonal and annual discharge regime.

This study represents a new contribution, and is motivated by a scientific interest to find out if the last ten years have changed the nature of the trends. In order to answer this question, the objective of our study is an analysis of long-term seasonal changes, i.e. trends, in specific runoff of rivers in Latvia within four hydrological regions, using the updated time series for the period 1951–2020.

Data and methods

A data series of daily discharge registered by 32 river hydrological station was used in this study (Figure 1). The data were obtained from the Latvian Environment, Geology and Meteorology Centre (LEGMC). Missing data were taken from CD (Zīverts & Strūbergs, 2000) or calculated from adjacent monitored river basin, using linear regression analysis where the coefficient of determination is $r^2 \geq 0.7$.

Specific runoff of rivers was used because it allows observed data from river basins of different size to be compared and results of statistical analysis to be assessed. Specific runoff was calculated as follows: discharge value distributed with catchment area and multiplied by 1,000. Monthly, seasonal and annual specific runoff values for the period of 1951–2020 were used. Seasons were defined as three months, as is usual in hydro-climatological studies: spring (MAM), summer (JJA), autumn (SON) and winter (DJF).

As a rule, hydrological data are not normally distributed and are characterised by positive skewness. Therefore, the non-parametric Mann-Kendall test is applied to detect trends in time series. The test is distribution-free and robust to missing data and outliers (Libiseller & Grimvall, 2002). In Europe, the Mann-Kendall test is the most widely used test of discharge trend analyses (Madsen et al., 2014). The trend magnitude was calculated by applying the non-parametric linear Sen's slope estimator.

The Theil–Sen estimator is more robust than the least-squares estimator because it is much less sensitive to outliers. Trend values are presented by changes per decade. The $p<0.05$ level was used for critical significance. Trends are considered statistically significant at $p<0.05$, $p<0.01$ and $p<0.001$ levels were presented in the results. The computer software program MAKESENS was used for calculating trends (Salmi et al., 2002).

The classification of hydrological regions by Glazacheva (1980) was used, according to which the country is divided into four regions: Western, Central, Northern and Eastern.

Figure 1. **Location of river hydrological stations and hydrological regions of Latvia. Hydrological regions: I- Western; II- Central; II- Northern and IV- Eastern** (I. Vinogradov's figure based on data from the LEGMC and Glazacheva, 1980)

Results and discussion

Results of the trend analysis by applying the Mann-Kendall test are presented in Table 1 in a generalised form within the four hydrological regions and in Latvia as a whole. If the mean trend value was positive, then all trends at the stations would also be positive and vice versa.

In the middle latitudes snow accumulation and melting presently dominate in the hydrological regime. Warmer winters are naturally related to higher runoff in winter and early maximum in spring after the snowmelt that is typical for the Baltic countries. Also in this study during 1951–2020, a major significant changes in specific runoff of rivers have observed in the winter and spring seasons in all hydrological regions and total in Latvia (Figure 2). In winter season the runoff of rivers increase (trend values varies from 0.55 to 1.22 L s^{-1} km^{-2} per $decade^{-1}$) and the trends are upward due to milder winters and early snowmelt. All changes are statistically significant at $p < 0.001$, but in the Eastern region at $p < 0.01$. At the same time, the trends obtained for the spring season are statistically insignificant, as the spring months (March, April and May) do not reveal the same pattern of change.

Table 1. **Trend values of spatially averaged monthly, annual and seasonal mean specific runoff of rivers (L s^{-1} km^{-2} per $decade^{-1}$) within each hydrological region and in Latvia as a whole in the period 1951–2020. Total number of stations for each hydrological region and Latvia as a whole is indicated in brackets** (authors' calculations based on data from the LEGMC and Zīverts & Strūbergs 2000)

	Hydrological region				Total in Latvia (32)
	Western (7)	Central (7)	Northern (10)	Eastern (8)	
Jan	1.49***	0.98***	1.00***	0.59**	1.01***
Feb	1.18**	0.88***	0.93***	0.63***	0.95***
Mar	1.11*	0.96**	1.46***	1.01***	1.17**
Apr	-1.13**	-1.72**	-1.46**	-1.30**	-1.37**
May	-0.10	-0.22	-0.35	-0.49*	-0.32
Jun	0.07	0.05	0.11	-0.07	0.03
Jul	0.08	0.08	0.12	0.03	0.08
Aug	0.02	0.01	0.00	-0.03	0.01
Sep	-0.03	-0.03	-0.07	-0.07	-0.08
Oct	0.03	-0.03	-0.10	-0.06	-0.04
Nov	0.25	0.15	0.43	0.16	0.31
Dec	0.42	0.40	0.52	0.27	0.45
Annual	0.19	0.03	0.22	0.01	0.12
Winter	1.22***	0.86***	1.04***	0.55**	0.92***
Spring	-0.36	-0.48	-0.30	-0.40	-0.39
Summer	0.05	0.04	0.09	-0.01	0.05
Autumn	-0.04	0.00	0.04	0.01	0.02

** p < 0.05 level of significance*
*** p < 0.01 level of significance*
**** p < 0.001 level of significance*

In the Western hydrological region, specific runoff of rivers increased more significantly in January and February. Moreover, in the Central, Northern and Eastern regions, more significantly runoff increase in January, February and March. All changes are at $p < 0.001$ and $p < 0.01$ levels of significance. The highest increase was detected in the Western district: trend values vary from 1.11 to 1.49 Ls^{-1} km^{-2} per decade^{-1}. The lowest increase was obtained in the Eastern region where trend values vary from 0.59 to 1.01 L s^{-1} km^{-2} per decade^{-1}.

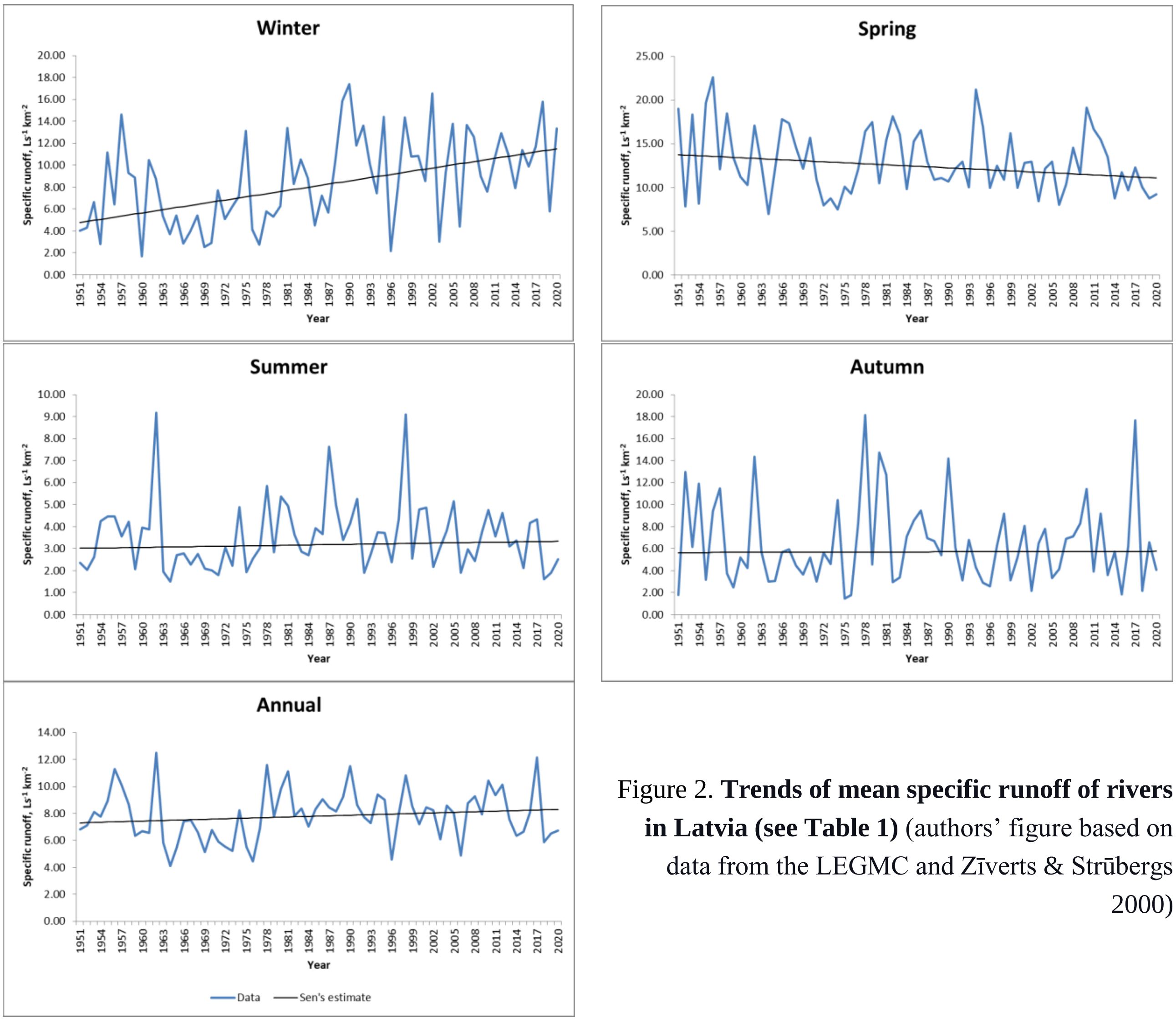

Figure 2. **Trends of mean specific runoff of rivers in Latvia (see Table 1)** (authors' figure based on data from the LEGMC and Zīverts & Strūbergs 2000)

Downward trend in streamflow was detected in April and May in all hydrological regions. Long-term changes are statistically significant at $p < 0.01$ in April and at $p < 0.05$ in May for the Eastern region. In April the highest decrease in specific runoff was detected for the Central region, where the trend value is -1.72 L s^{-1} km^{-2} per decade^{-1}. The lowest decrease in runoff was observed for the Western region, where the trend value is -1.13 L s^{-1} km^{-2} per decade^{-1}.

In the Western part of Latvia, greater impact of meteorological processes occurring over the North Atlantic and the Baltic Sea on the river hydrological regime is observed than for other parts in Latvia. This influence decreases from west to east with the eastward increase of continentality. Furthermore, in western and central hydrological regions comparatively shorter ice-cover and thinner snow cover was also observed, resulting in earlier onset of spring flooding. The Eastern region is characterised by more continental climate conditions than the others, i.e. warmer summers and colder winters with thick snow cover. Spring floods of rivers begin later and their duration is longer (Apsite et al., 2013).

Generally, statistically insignificant trends in specific runoff are observed for summer and autumn months. However, mean specific runoff has significantly increased in some rivers (e.g. in the rivers Venta, Imula, Lielupe, Mūsa, Salaca and Aiviekste) in June and July. This could be due to an increase in precipitation in June for the Western, Central and Eastern regions for the period 1950–2020. Another specific feature emerges: the river runoff decreased in September and October. The highest decrease in trend values was detected in the Eastern region while the lowest decrease was seen in the Western region. According to Jaagus et al. (2016) this could be explained by warmer autumns, and increased evapotranspiration and decreased precipitation in September.

Similar to the findings in a study conducted in Estonia (Jaagus et al., 2017), our results indicate that, despite the increase in precipitation and temperature, the annual mean specific runoff did not show any significant trends. A statistically significant change in runoff was found in some rivers (the rivers Lielā Jugla, Salaca and Vaidava) and in Western region (the rivers Irbe, Užava and Rīva).

The results of this study are in line with previous studies in the Baltic countries (e.g. Kļavinš et al., 2009; Reihan et al., 2012; Kriaučiūniene et al., 2012; Apsīte et al., 2013; Jaagus et al., 2017), indicating major significant long-term changes in river runoff during the last few decades between the winter and spring seasons.

Conclusion

Changes in streamflow during the 20th century and the beginning of the 21th century revealed a redistribution of runoff over the year, with a significant increase in winter in all hydrological regions and a tendency for decreasing spring floods particularly in the Central and Eastern hydrological regions. In this study, by using the updated time series of 1951–2020, the trends in river runoff duration in Latvia has not changed very much in comparison with the results of the previous study for the period 1951–2009. The obtained results of trend analysis could be considered as logical consequences of the climate warming that is projected in Latvia.

Kopsavilkums

Tas, ka globālais klimats kļūst aizvien siltāks, ir būtiski ietekmējis hidroloģiskos procesus, tajā skaitā upju noteces ilgtermiņa pārmaiņas vai trendus pēdējās desmitgadēs. Šajā pētījumā ir analizētas Latvijas upju īpatnējās noteces mēnešu, sezonu griezumā, kā arī ikgadējie trendi par 32 upju hidroloģiskajām stacijām no 1951. līdz 2020. gadam, izmantojot Manna-Kendella testu un Sen's metodi. Rezultāti apkopoti un analizēti četros hidroloģiskajos

rajonos: Rietumu, Centrālajā, Ziemeļu un Austrumu, kā arī Latvijā kopumā. Pētījums parādīja, ka būtiskākās upju noteces pārmaiņas ilgtermiņā notikušas ziemas un pavasara sezonā visos hidroloģiskajos rajonos. Palielinoties izkritušo nokrišņu daudzumam ziemā, upju īpatnējā notece ir augusi no 0,6 līdz 1,2 L s^{-1} km^{-2} desmit gados, kur lielākās pārmaiņas novērotas Rietumu hidroloģiskajā rajonā, bet mazākās – Austrumu. Savukārt upju notece samazinājusies pavasarī no 0,32 līdz 0,46 L s^{-1} km^{-2} desmit gados. Noteces samazinājums galvenokārt ir noticis aprīlī un maijā, kas norāda, ka gada maksimālā notece sāk veidoties agrākos mēnešos. Vasarā upju īpatnējā notece ir nedaudz palielinājusies, jo ir kļuvis lielāks izkritušo nokrišņu daudzums tieši jūnija mēnesī. Savukārt rudeņiem kļūstot siltākiem un sausākiem, upju notece samazinājusies septembrī un oktobrī. Salīdzinot iegūtos rezultātus ar agrāk veiktajiem pētījumiem Baltijas valstīs, var secināt, ka Latvijas upju noteces trendu galvenās raksturiezīmes saglabājas tādas pašas un tādas tās turpinās attīstīties līdz ar klimata pasiltināšanos.

References

Apsīte, E., Rudlapa, I., Latkovska, I. and Elferts, D. (2013). Changes in Latvian river discharge regime at the turn of the century. *Hydrology Research*, 44 (3), 554–569. doi:10.2166/nh.2012.007

BACC Author Team (2008). *Assessment of climate change for the Baltic Sea basin*. Berlin, Heidelberg: Springer.

BACC II Author Team (2015). *Second assessment of climate change for the Baltic Sea Basin*. Cham, Heidelberg, New York, Dordrecht and London:Springer.

Glazacheva, L. (1980). *Hydrological Regions. The Elaboration of Methodology*. University of Latvia, Riga (in Russian).

Jaagus, J., Briede, A., Rimkus, E. and Sepp, M. (2016). Changes in precipitation regime in the Baltic countries in 1966–2015. *Theoretical and Applied Climatology*, 131, 433-443. https://doi.org/10.1007/s00704-016-1990-8

Jaagus, J., Sepp, M., Tamm, T., Järvet, A. and Mõisja, K. (2017). Trends and regime shifts in climatic conditions and river runoff in Estonia during 1951–2015. *Earth System Dynamics*, 8, 963–976. https://doi.org/10.5194/esd-8-963-2017

Kļaviņš, M. and Rodinov, V. (2008). Long-term changes of river discharge regime in Latvia. *Nordic Hydrology*, 39 (2), 133–141.

Kļaviņš, M., Briede, A. and Rodinov, V. (2009). Long term changes in ice and discharge regime of rivers in the Baltic region in relation to climatic variability. *Climatic Change*, 95, 485–498.

Kriaučiūniene, J., Meilutyte-Barauskiene, D., Reihan, A., Koltsova, T., Lizuma, L. and Sarauskiene, D. (2012). Variability of regional series of temperature, precipitation and river discharge in the Baltic States. *Boreal Environmental Research*, 17, 150–162.

Libiseller, C. and Grimvall, A., (2002). Performance of Partial Mann Kendall Tests for Trend Detection in the Presence of Covariates. *Environmetrics*, 13, 71-84.

Madsen, H., Lawrence, D., Lang, M., Martinkova, M. and Kjeldsen, T.R. (2014). Review of trend analysis and climate change projections of extreme precipitation and floods in Europe. *Journal of Hydrology*, 519, 3634–3650.

Meier, H. E. M., Kniebusch, M., Dieterich, C., Gröger, M., Zorita, E., Elmgren, R., Myrberg, K., Ahola, M.P., Bartosova, A., Bonsdorff, E., Börgel, F., Capell, R., Carlén, I., Carlund, T., Carstensen, J., Christensen, O.B., Dierschke, V., Frauen, C., Frederiksen, M., Gaget, E., Galatius, A., Haapala, J.J., Halkka, A., Hugelius, G., Hünicke, B., Jaagus, J., Jüssi, M., Käyhkö, J., Kirchner, N., Kjellström, E., Kulinski, K., Lehmann, A., Lindström, G., May, W., Miller, P.A., Mohrholz, V., Müller-Karulis, B., Pavón-Jordán, D., Quante, M., Reckermann, M., Rutgersson, A., Savchuk, O.P., Stendel, M., Tuomi, L., Viitasalo, M., Weisse, R. and Zhang, W. (2022). Climate change in the Baltic Sea region: a summary. *Earth System Dynamics*, 13, 457–593. https://doi.org/10.5194/esd-13-457-2022

Reihan, A., Koltsova, T., Kriauciuniene, J., Lizuma, L. and Meilutyte-Barauskiene, D. (2007). Changes in water discharges of the Baltic states rivers in the 20th century and its relation to climate change. *Nordic Hydrology*, 30 (2), 109–128.

Reihan, A., Kriaučiūniene, J., Meilutyte-Barauskiene, D. and Koltsova, T. (2012). Temporal variation of spring food in rivers of the Baltic states. *Nordic Hydrology*, 43 (4), 301–314. doi:10.2166/nh.2012.141

Sarauskiene, D., Kriauciuniene, J., Reihan, A., and Klavins, M. (2015). Flood pattern changes in the rivers of the Baltic countries. *Journal of Environmental Engineering and Landscape Management*, 23 (1), 28-38. https://doi.org/10.3846/16486897.2014.937438

Salmi, T., Määttä, A., Anttila, P., Ruoho-Airola, T. and Amnell, T. (2002). Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimate - The Excel template application MAKESENS. *Publications on Air Quality 31*. Helsinki: Finnish Meteorological Institute.

Zīverts, A. and Strūbergs, J. (2000). *Hidroloģiskie aprēķini Latvijā* (CD). Jelgava: LLU.