Long-term changes of river discharge regime in Latvia

Maris Klavins and Valery Rodinov

ABSTRACT

The study of changes in river discharge is important for regional climate variability characterization and for development of an efficient water resource management system. The hydrological regime of rivers and their long-term changes in Latvia were investigated. Four major types of river hydrological regimes, which depend on climatic and physicogeographic factors, were characterized. These factors are linked to the changes observed in river discharge. Periodic oscillations of discharge, and low- and high-water flow years are common for the major rivers in Latvia. A main frequency of river discharge regime changes of about 20 and 13 years was estimated for the studied rivers. A significant impact of climate variability on the river discharge regime has been found.

Key words | discharge, Latvia, long-term variability, trends

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INTRODUCTION

Considering the increasing human impact on the environment, studies of environmental change are of the utmost importance. Long-term observations of hydrologic systems provide time series of evapotranspiration, precipitation and river discharge. These data series can be analysed from different points of view. For example, the study of the hydrological cycle is important in the investigation of climatic variation and in hydrological applications (Arnell 1992). Considerable attention has been paid to the study of global climate change, to relations between global processes of atmospheric circulation (NAO, ENSO) and to the hydrological cycle (Perry *et al.* 1996; Amarasekera *et al.* 1997; Simpson & Colodner 1999), as well as the regional impacts of global climatic changes (Gleick 1986). Future climatic changes may have substantial impacts on river discharge patterns, as well as on extreme events, their magnitude and probability of occurrence (Krasovskaia & Gottschalk 1993). River discharge data can also be used to validate hydrological cycle calculations in climate models (Zeng 1999).

Commonly, river discharge patterns have been studied in terms of linear trend analysis, even though they can be much more complex (Pekarova *et al.* 2003). Analysis of river discharge patterns is important for the Baltic countries, which are located in a climatic region directly influenced both by atmospheric processes in the Northern Atlantic and by continental impacts from Eurasia.

The earliest observations of river discharge in Latvia can be dated back to the 19th century for the River Daugava, and long series of data have been accumulated. Studies conducted on river discharge trends in Estonia confirm the importance of such analysis (Jaagus *et al.* 1998). Long-term stream flow analysis is essential for effective water resource management and therefore has immense socio-economic significance. Discharge analysis in respect to global climatic changes is also presently important considering the predicted changes in this region.

The aim of the present study is to analyse the hydrological regime and long-term changes of river discharge in Latvia.

METHODS

The study area covered the whole territory of Latvia (Figure 1), but also reference sites of rivers in neighbouring areas were used. In Latvia, there is a dense net of rivers flowing

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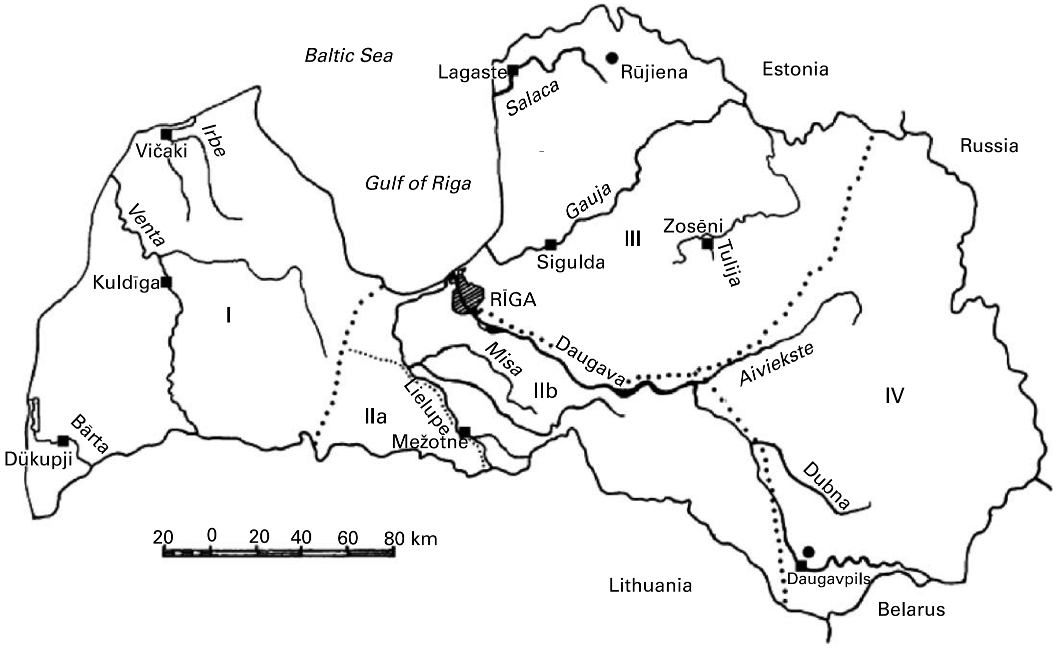


Figure 1 | Hydrologic regions of Latvia (I–IV), water discharge (■) and air temperature and precipitation (•) stations.

through Quaternary sediments. The total number of rivers is 12 500, of which only 17 are longer than 100 km. The total length of the rivers is ~ 37 950 km and the mean density of the river network is 588 m per 1 km^2. The average annual runoff of rivers is about 35 km^3, of which more than 50% forms in neighbouring countries. The hydrological regime in rivers is influenced not only by the climate (precipitation and air temperature), but also by factors such as geomorphology, geological structure, soil composition and land-use patterns (Table 1). The coverage of lakes and wetlands in river basins also affects the river stream flow. More than 90% of the total runoff in Latvia is through the five largest rivers. In general, the dominance of the natural environment indicates a rather low level of anthropogenic impact.

Commonly, watercourses have not been subjected to major anthropogenic pollution, with the exception of the lowest reaches of the rivers and selected sites on the River Daugava below large cities such as Daugavpils, Līvāni and others (Klavins *et al.* 1999).

The climatic conditions for Latvia are dominated by transport of cyclonic air masses from the Atlantic Ocean, leading to comparatively high humidity, uneven distribution of atmospheric precipitation through the year, mild winters and moist summers. In general, the spatial heterogeneity of

Table 1 | Characteristics of the studied rivers

River	Basin size (km^2)	Length (km)	Water runoff (km^3/yr)	Forest area (%)	Bog area (%)	Agricultural area (%)
Daugava	87,900	1005	20.4	43	5	50
Lielupe	17,600	119	3.6	22	3	71
Venta	11,800	346	2.9	32	5	62
Gauja	8900	452	2.2	47	5	48
Salaca	3420	95	0.95	34	15	45
Bārta	2020	98	0.63	55	7	38
Irbe	2000	32	0.44	63	8	29
Tulija	57	15	0.018	52	4	44

the climate of Latvia is determined by physiogeographical features, such as upland relief, distance to the Baltic Sea, and coverage of forests and mires. More precipitation is common for uplands ($>$ 200 m a.s.l.), and differences between regions can reach up to 250 mm annually. For climate characterization monthly temperature and precipitation of Daugavpils (in the SSE of Latvia) and Rūjiena (in the NE of Latvia) meteorological stations have been represented (Figure 2). For centenary trend estimation of the air temperature and precipitation, data from the Meteorological Station Rīga-University were used (Figure 3). Data used in this study were obtained from the Latvian Environmental, Geological and Hydrometeorological Agency.

Discharge measurements covered the last 65 years for the River Gauja and 125 years for the River Daugava. For trend analysis, mean annual discharge values calculated as arithmetic means from monthly records were used.

The stream flow data before analyses of variability have been tested by the Fisher test for data homogeneity (Table 2).

The length of observation has been divided into two periods (before and after 1960) that differs by intensity of agricultural activities. Obtained results indicated that the time series of river flow are homogenous ($F_{\text{emp}} < F_{\text{theoretical}}$, $p = 0.05$) for all selected rivers.

For the calculation of the periodic changes (oscillation) of discharge, moving average (step 6 and 10 years) values of discharge data as well as integral curves were utilized. The use of integral curves, which depict differences in discharge for each study year in comparison with mean values for all the observation period, allows us to identify the pattern of discharge changes. In the calculation, the ratio K was used:

$$K = \frac{Q_i}{Q_0}$$

where Q_i is discharge in year i and Q_0 is the mean discharge for the entire period of observation.

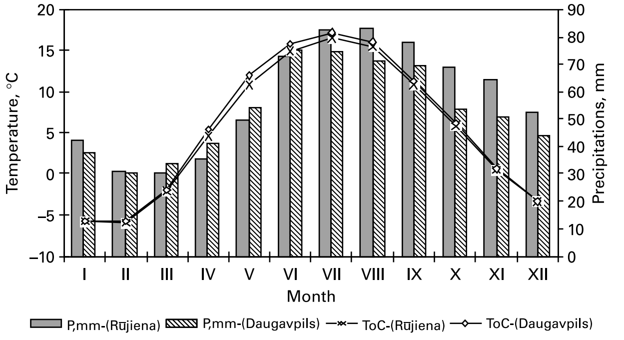


Figure 2 | Monthly changes of temperature and precipitation in common observation stations (Rūjiena and Daugavpils).

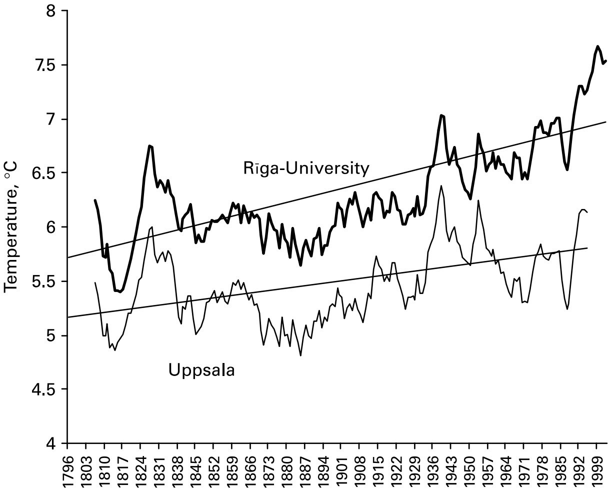


Figure 3 | Long-term changes of temperature in Riga (Latvia) and Uppsala (Sweden).

Table 2 | Results of Fisher test statistics

River	Number of observations	Standard deviation	F_{emp}	$F_{\text{theoretical}}$	p (%)
Salaca, 1927–1959	33	10.51	1.10	1.76	0.05
Salaca, 1960–2004	45	9.68			
Gauja, 1940–1959	20	14.55	1.87	1.99	0.05
Gauja, 1960–2004	45	18.99			
Daugava, 1920–1959	40	115.35	1.02	1.69	0.05
Daugava, 1960–2004	45	113.11			
Lielupe, 1921–1959	39	20.95	1.60	1.71	0.05
Lielupe, 1960–2004	45	17.03			
Venta, 1920–1959	40	17.33	1.45	1.70	0.05
Venta, 1960–2004	45	20.47			

Using this approach, the integral curve is produced by summing these deviations $\sum(K-1)$. By integration of the deviations, the amplitude of the oscillations increases proportionally to the length of the period, with one-sign deviations in the row. The analyses of integral curves allow us to precisely identify significant change points of low-water and high-water discharge periods. High-water discharge periods are considered to be years for which $K > 1$ and low-water flow periods are indicated by $K < 1$. For data treatment, the Excel, SPSS and Multimk software packages were used.

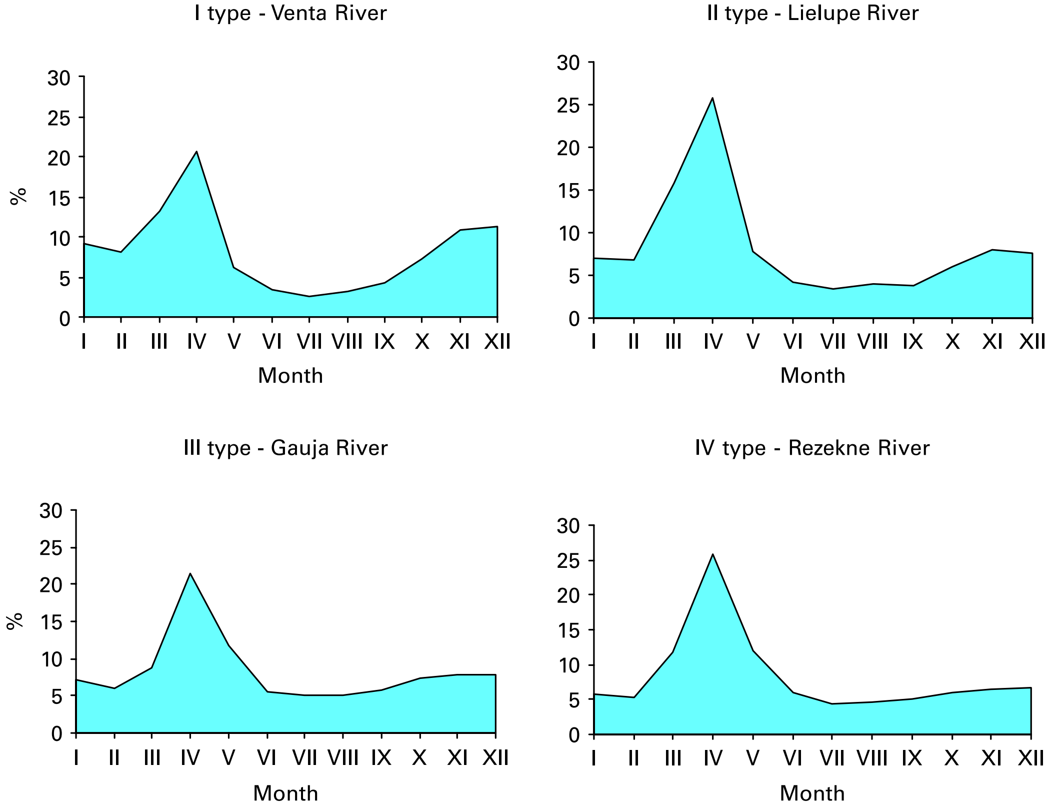
The multivariate Mann–Kendall test (as described by Hirsch *et al.* (1982) and Hirsch & Slack (1984) for monotone trends in time series of data grouped by sites was chosen for the determination of trends, as it is a relatively robust method concerning missing data, and it lacks strict requirements regarding data heteroscedasticity. The Mann–Kendall test was applied separately to each variable at each site, at a significance level of $p < 0.5$. The trend was considered as statistically significant at the 5% level if the test statistic was greater than 2 or less than -2 (Hirsch & Slack 1984).

RESULTS AND DISCUSSION

Depending on the hydrological regime, the river basins in Latvia can be grouped into the four hydrological regions shown in Figure 1. The hydrological regions differ in the seasonal river discharge variability in spring and autumn, by the relative proportion between spring and autumn floods (Figure 4), and also in other factors (precipitation, evapotranspiration, runoff, temperature):

Type I. The River Venta and small rivers along the coast of the Baltic Sea. The rivers in this region have two main discharge peaks – during the spring snow melt and in the late autumn during intensive rainfall.

Type II. The River Lielupe and small rivers in central part of Latvia. This group of rivers receives the major part of their discharge from direct surface runoff. Spring floods


I type - Venta River

II type - Lielupe River

III type - Gauja River

IV type - Rezekne River

Figure 4 | Patterns of seasonal river discharge for major rivers in Latvia.

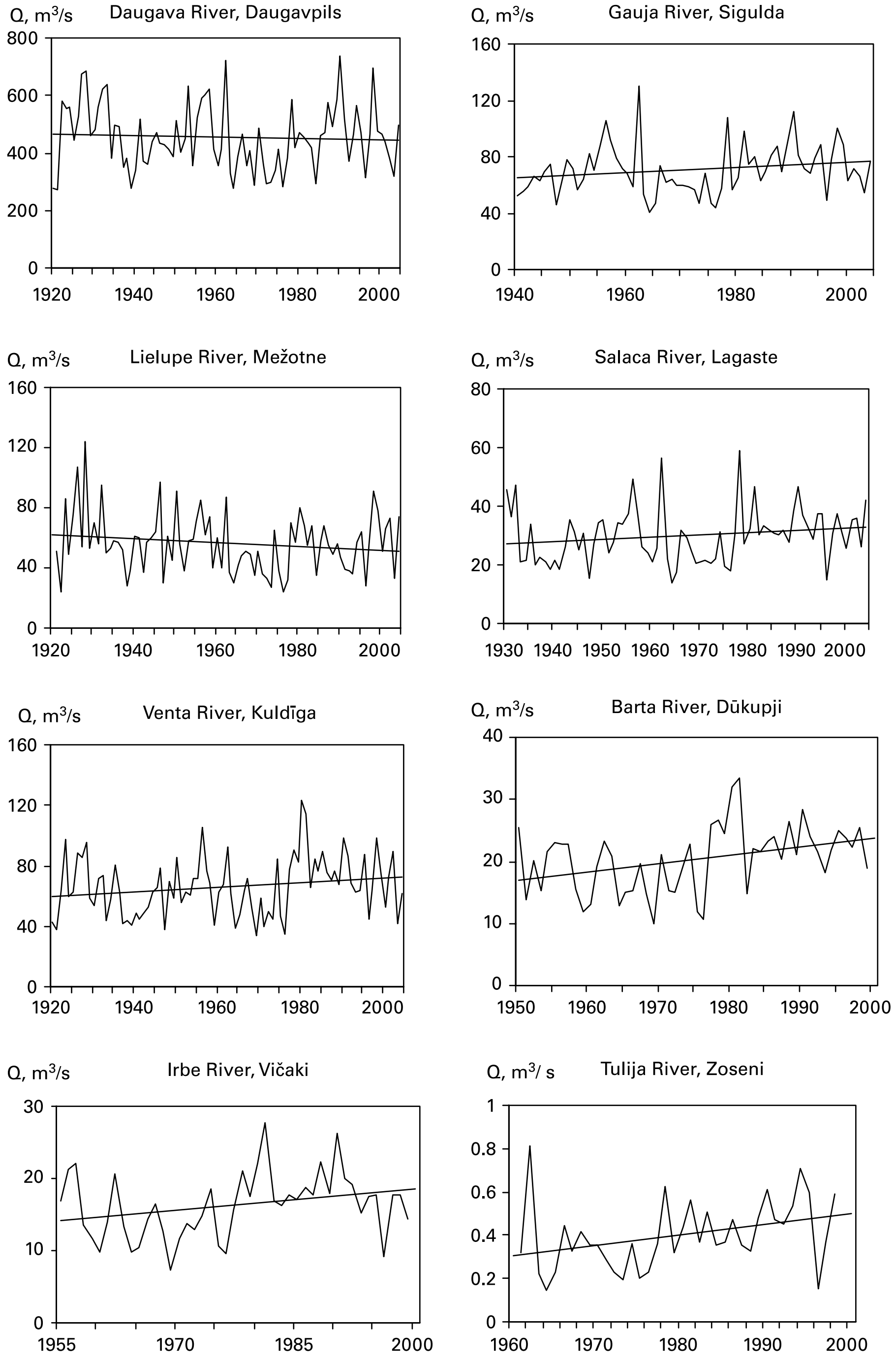


Figure 5 | Long-term changes of river discharge in Latvia.

dominate, and the role of permanent water discharge during the year is comparatively low (~ 40%).

Type III. Basins of the River Salaca, River Gauja, and small rivers along the Rīga Gulf coast. This group of rivers is characterized by substantial snowmelt floods and comparatively smaller (than type I) rain floods in autumn. 50–60% of the total runoff takes place in spring.

Type IV. Small- and medium-sized rivers in the basin of

River Daugava (as it can be seen for example for the River Rēzekne). More than half of the river discharge takes place during spring floods, and the water discharge pattern is characterized by steep fluctuations of water discharge.

Differences in annual precipitation in Latvia range from 63% to 150% in comparison with the mean values. More precipitation occurs in the warm period (IV–X) of the year, reaching 63–70% of the annual total. Mean air temperature decreases in the direction from the West to East. Inter-annual temperature variability (mean value 22.5°C, maximum 34°C), as well as intra-annual, has comparatively small significance.

Changes in river discharge were determined using linear trend analysis with the commonly used approach in the study of river discharge. Figure 5 and Table 3 shows that the discharge trends in rivers of Latvia and the north-eastern part of the Baltic Sea are evident: the discharge has significantly increased for the rivers Venta, Gauja, Bārta, Irbe and Tulija and the changes are significant and increasing for all of the other studied rivers only after 1960.

It is also evident that river discharge is characterized by a stronger increase if the period of trend analysis is reduced to the last 50 years. It should be mentioned that discharge trends and trends for precipitation and temperature are similar for hydrological regions II, III and IV. Regarding the River Venta, located in the type I hydrological region, a positive trend of discharge is more expressed. The long-term trends of seasonal river discharge indicate that most of the increase happens during the winter season (Figure 6). The river discharge (for example, the Daugava, Venta and Lielupe rivers) in winter (December–February) shows a significantly increasing trend. A particularly significant increase in winter discharge can be observed during the last two decades.

An observation period of more than 150 years at the Meteorological Station Riga-University (Figure 3) shows that, over the last century, the mean annual temperature has increased by about 0.8°C. Using moving average values (6 years), good coherence is seen between changes in annual precipitation at the Meteorological Station Riga-University and discharges of the largest rivers in Latvia (Figure 7).

The use of integral curves allows us better to identify oscillation patterns. Figure 8 shows integral curves for water discharge in the five largest rivers in Latvia. Differences are seen among the Lielupe and the other four rivers in Latvia, and in all rivers there is an apparent difference between observations before and after 1920. For example, in the River Lielupe, water discharge decreased from 1986 to 2000, in contrast to the other rivers that showed a stable increasing tendency. As can be seen from Figure 8, in 1996 the water discharge reached its lowest value during the last ten years in rivers in Latvia. The difference in flow patterns between the River Lielupe and other rivers in Latvia can also be explained by considering that the discharge station in Lielupe is situated quite upstream (110 km) and thus can reflect slightly more than 50% of the total river discharges. The Lielupe River basin is moderately affected by ameliora-

Table 3 | Significance test for temporal changes of water discharge for rivers in Latvia

River, sampling station	Period of observation	Normalized test statistic	Period of observation	Normalized test statistic
Daugava–Daugavpils	1905–2004	−1.16	1961–2004	2.41
Venta–Kuldīga	1905–2004	2.39	1961–2004	1.09
Lielupe–Mežotne	1920–2004	−0.91	1961–2004	1.94
Gauja–Sigulda	1939–2004	1.82	1961–2004	2.50
Salaca–Lagaste	1926–2004	1.07	1961–2004	2.79
Aiviekste–Lubāna	1959–1999	1.65	1961–2003	2.25
Dubna–Sili	1948–1998	1.57	1961–1999	3.00
Barta–Dūkupji	1950–1999	2.35	1961–1999	2.53
Irbe– Vičaki	1955–1999	2.19	1961–1999	2.67
Tulija–Oļi			1961–2004	2.85

The trend can be considered as statistically significant at the 5% level if the test statistics is greater than 2 or less than −2.

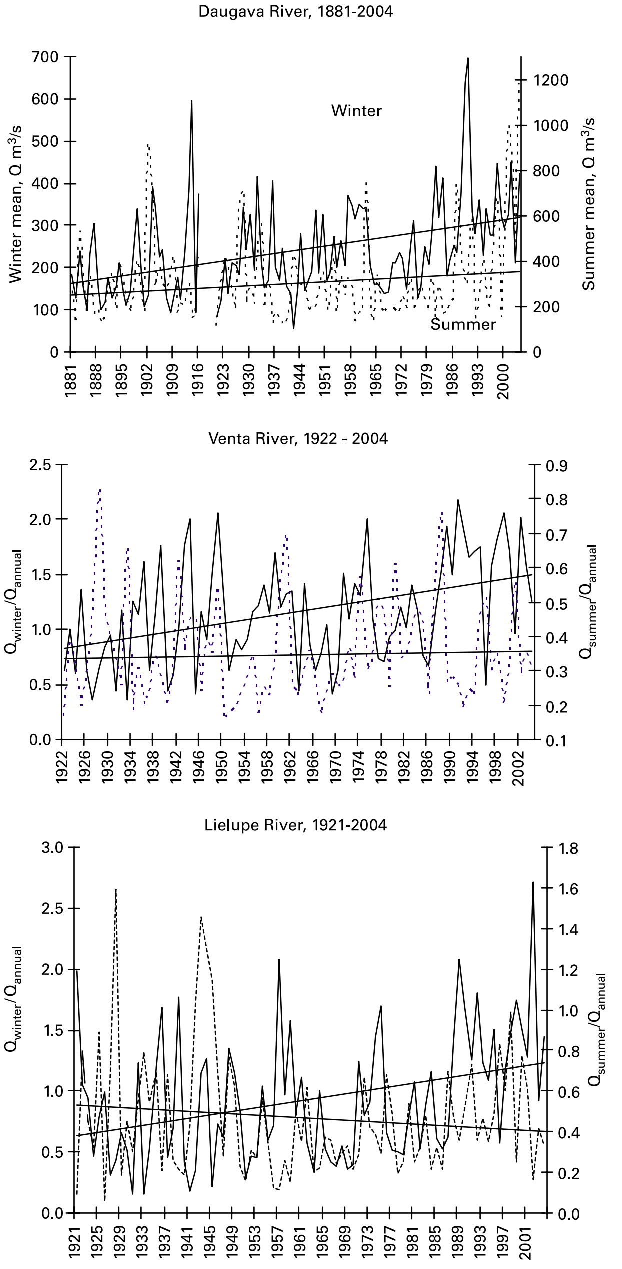


Figure 6 | Long-term changes of winter (—) and summer (···) discharge ratios in respect to mean annual discharge in the rivers Daugava, Venta and Lielupe.

tion and by various hydrotechnical constructions (dams, ponds, etc.). Also agricultural activities influence the water flow regime in this river.

General patterns of the periodicity of water flow regime in several major rivers in Latvia are summarized in Table 4.

For last 100–125 years low discharge periods for the rivers in Latvia are longer than high discharge periods and

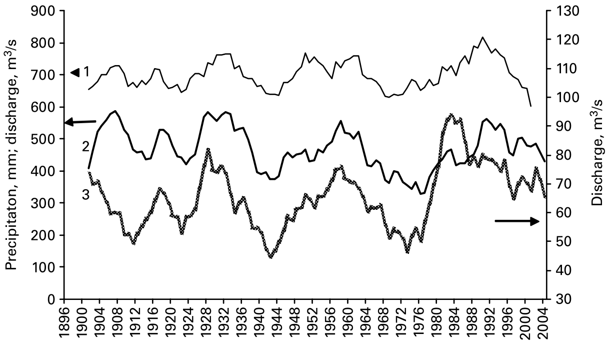


Figure 7 | Long-term changes of mean annual discharge of the rivers and precipitation in Latvia. 1, precipitation (Station Riga-University); 2, discharge River Daugava; 3, discharge River Venta. Data were smoothed by 6 year moving average.

they last from a minimum of 10 years up to a maximum of 21–27 years. In the same time high discharge periods last from 10 years (6–8 years), but during the last 30 years for the biggest rivers (except Lielupe) their prolongation can reach even 20–27 years. Goudie (1992) described sinusoidal changes of river discharge in Eastern Europe. An approximately 20 year periodicity has been suggested in earlier studies for rivers in the Baltic region and Eastern Europe (Glazacheva 1988), along with a period of about 20–50 years for monthly mean precipitation and water level which may be the result of interference of the precipitation and temperature regimes. In previous studies, a 26 year periodicity of River Daugava flow was considering as the main period, which includes 2, 6 and 13 year smaller cycles (Glazacheva 1988). However, there is no well-defined explanation of the physical meaning of the river discharge regime.

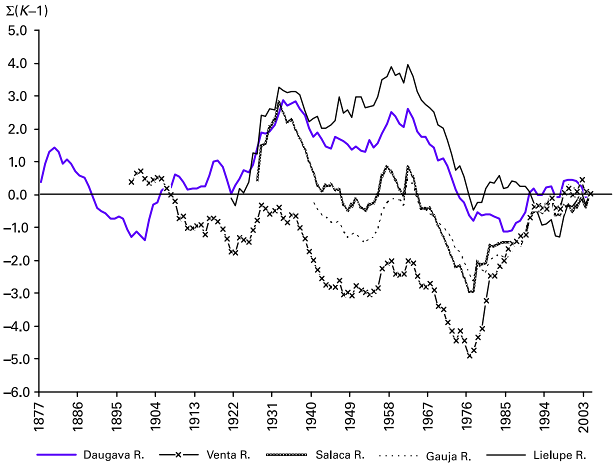


Figure 8 | Normalized integral curves for coefficients of the annual runoff of rivers in Latvia.

Table 4 | Changes of low and high discharge periods for largest rivers in Latvia

Low discharge period	Years	Q_{mean} (m^3/s)	K	High discharge period	Years	Q_{mean} (m^3/s)	K
Daugava (1881–2004)							
1881–1901	21	401	0.87	1902–1908	7	595	1.29
1909–1921	13	442	0.96	1922–1936	15	549	1.19
1937–1952	16	419	0.90	1953–1958	6	555	1.20
1959–1985	27	401	0.87	1986–2004	19	490	1.06
Total, mean	*77*	*416*	*0.90*		*47*	*547*	*1.18*
Venta (1897–2004)							
1900–1923	24	60.2	0.92	1924–1930	7	72.1	1.10
1931–1949	19	57.0	0.87	1950–1959	10	69.9	1.07
1960–1977	18	57.1	0.88	1978–2002	25	79.1	1.21
Total, mean	*61*	*58.1*	*0.89*		*42*	*73.7*	*1.13*
Salaca (1927–2004)							
1933–1952	20	25.6	0.84	1927–1932	6	44.9	1.48
1963–1976	14	22.4	0.74	1953–1962	10	34.6	1.14
				1977–2004	28	33.9	1.11
Total, mean	*34*	*24.0*	*0.79*		*44*	*37.8*	*1.24*
Gauja (1940–2004)							
1940–1952	13	62.5	0.89	1953–1962	10	84.5	1.21
1963–1977	15	55.8	0.80	1978–2004	27	77.4	1.10
Total, mean	*28*	*59.2*	*0.84*		*37*	*81.0*	*1.15*
Lielupe (1921–2004)							
1933–1942	10	49.4	0.89	1921–1932	12	71.9	1.29
1963–1977	15	39.8	0.72	1943–1962	20	61.8	1.11
1984–1997	14	48.9	0.88	1978–1983	6	66.3	1.19
				1998–2004	7	66.8	1.18
Total, mean	*39*	*46.0*	*0.83*		*45*	*66.7*	*1.20*

Table 5 | Correlation between river discharge, precipitation, temperature and the North Atlantic oscillation index

	Daugava	Venta	Lielupe	Gauja	Salaca	Temperature	Precipitation	NAO annual
Venta	0.460[†]							
Lielupe	0.540[†]	0.637[†]						
Gauja	0.800[†]	0.672[†]	0.624[†]					
Salaca	0.666[†]	0.719[†]	0.671[†]	0.891[†]				
Temperature	−0.132	0.078	−0.095	0.118	0.018			
Precipitation	0.295[†]	0.435[†]	0.266[*]	0.387[†]	0.495[†]	0.065		
NAO annual	−0.010	0.160	0.100	0.231	0.225[*]	0.396[†]	0.172	
NAO winter	0.093	0.157	0.166	0.311[*]	0.319[†]	0.508[†]	0.209[*]	0.493[†]

[*] Correlation is significant at the 0.05 level (2-tailed).

[†] Correlation is significant at the 0.01 level (2-tailed).

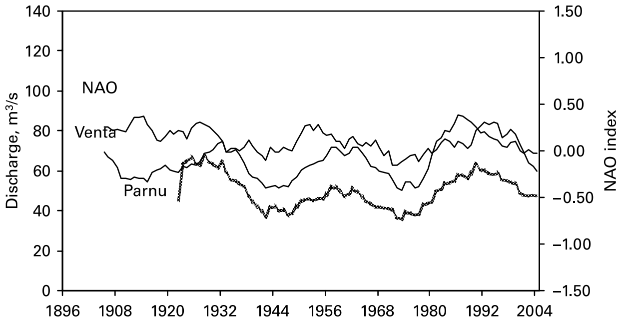


Figure 9 | Long-term changes of River Venta and River Pärnu discharges and index of North Atlantic oscillation (data were smoothed with a 10 year moving average).

It is important to recognize that the assessment of factors driving changes of river discharge is far beyond the aims of this paper as, basically, these questions are a part of the global climate change problems. Long-term changes of river discharge patterns can be directly related to changes in the North Atlantic oscillation (Table 5, Figure 9). It can be only a guess about factors determining the oscillatory pattern of river discharge, it can cause us to reconsider conclusions made on short-term observations and also conclusions when analyzing river discharge changes only as a linear process.

CONCLUSIONS

The river discharge regime in Latvia during the last century has been subjected to major changes, highly possible due to climate variability. In the same time well-expressed regular changes of high water and low water periods are evident.

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