LONG-TERM CHANGES OF INLAND WATER QUALITY IN LATVIA DEPENDING ON HUMAN IMPACTS

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ABSTRACT
Long-term changes of aquatic chemistry in rivers of Latvia have been evaluated in respect to fluctuation of river discharge and changes of human loading. Water composition, the major factors influencing water chemistry, and the human impacts were studied to determine the character of changes after recent reductions of pollution emissions, particularly nutrient loading, to surface waters. The trends of major water ingredients were calculated. The found patterns of interdependence between water chemical composition and river discharge, considers long-term oscillatory pattern of the latter, major impacts of discharge extremes for inorganic (conservative) ingredients and labile ingredients (organic matter and nutrients) and comparatively fast response on changes of loading which reflect impact of human activities and differs between eastern and western Latvia.

Key words: trends, aquatic chemistry, discharge, runoff, Latvia

INTRODUCTION
Analysis of long-term changes of aquatic chemistry and loading of dissolved substances is of importance to study the human impact and general contamination levels in river and lake basins, for evaluation of efficiency of monitoring systems and to support necessary management activities often aimed at reduction of loading of toxic and undesired substances. The need to evaluate integrated dimensions of adverse processes in waterbodies and the mobility of substances, increase the importance of studies of long-term changes in aquatic chemistry. Often of especial importance are studies of changes of nutrient concentrations and loading, considering common eutrophication of coastal waters and inner seas. Analysis of loadings of dissolved substances is an objective of national and international environmental legislation, international agreements, and there are many legislative acts aimed at reduction of loading of undesired substances, at first persistent pollutants and nutrients, legislation of EU in this area mentioning as an example. Considering importance of loading regulation there are many studies dedicated to analysis of factors controlling loading from continent to seas and trend analysis of loadings (Zhang et al., 1995; Linthurst et al., 1986). Loadings of nutrients and their trends for comparatively short time periods (usually not longer than 5 – 10 years) has been much studied for the Baltic Sea area, considering sensitivity to eutrophication and intensive loading (Löfgren et al., 1999; Kļaviņš et al., 1999). However, the aquatic chemistry depends on discharge regime, but river discharge can much fluctuate not only within a year, but also for longer periods and is subjected to global climate change processes. Long-term fluctuations of river discharge can influence also loading of dissolved substances, but in the previous studies it has not been considered.

In the case of Latvia, it can be possible to link changes in the environment with changes in society – to identify environmental consequences of changes of loading to surface waters. The changes were particularly rapid since 1991 as a result of the transformation of the industrial and agricultural production system. This transformation was associated with economic recession and with a reduction in loads to the environment (Kļaviņš and Cimdiņš, 1995; Löfgren et al., 1999).

The objective of the present study was to study long-term changes of aquatic chemistry in surface waters of Latvia in relation to long-term changes of river discharge and recent reduction of loading to water bodies.

METHODS
Data used in the study were obtained from the Latvian Hydrometeorological Agency, and Department of Environmental Sciences of the University of Latvia. Monthly records for the whole study period (1975-2002) (Yearly bulletins, 1976-2001) as well as laboratory reports on the water chemical composition were available. During the study period, the sampling and analytical methods followed standard methods (Tsirkunov et al., 1992). From 1972-1993, water ingredients were analyzed according to standard methods used in the USSR. More or less substantial changes in the analytical equipment and methods used have occurred during all period of observations. Since 1997, national analytical methods based on ISO standards began to be introduced. Locations of sampling sites and regular monitoring stations are shown on Figure 1.

The multivariate Mann-Kendall (Hirsch et al., 1982; Hirsch and Slack, 1984; Libiseller and Grimvall 2002) test for monotone trends in time series of data grouped by sites, plots and seasons was chosen for 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 (program MULTIMK/CONDMK) 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.

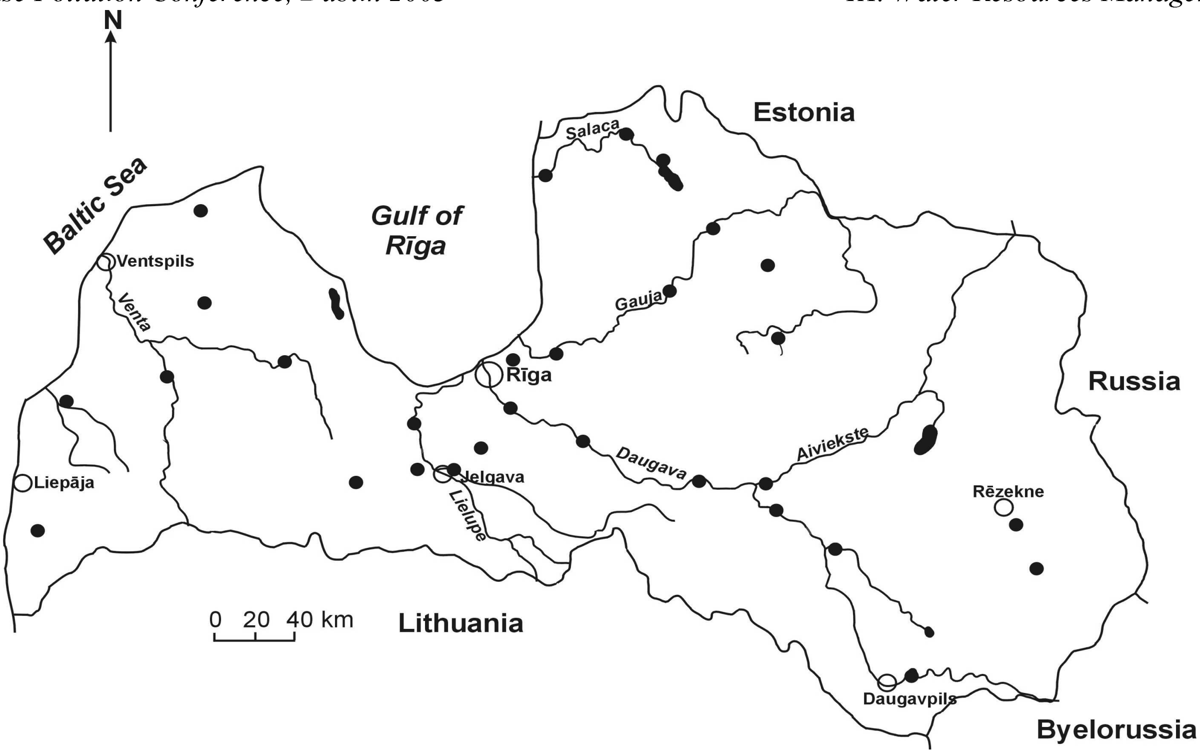


Figure 1. Study area and river water quality monitoring stations

RESULTS AND DISCUSSION

The aquatic chemistry and biology of inland waters of Latvia are determined by its physico-geographic location: flat surface topography (57 % of Latvia's territory is located below 100 m above sea level), dominance of Quaternary glacial and ancient sea sediments (parent soil materials are moraine loam and sands), and dominance of humic podsol soils. In Latvia's location by the Baltic Sea, the climate is wet and comparatively cold climate (the mean precipitation ranges from 600 to 900 mm per year) and the area supports a dense net of rivers (total number of rivers is 12 500, and the mean density of the river network is 588 m per 1 km^2). The dimension of human impacts is determined by the intensity of land use. Forest coverage is 44.9 %, the density of settlements is low (32.5 % of the population is concentrated in Riga and 17.3 % in the other larger cities), and the dominant land-use type is agricultural. The selected river and lake basins are representative of Latvia in their aquatic chemistry and land-use patterns, but also several representative small rivers were considered in aquatic quality studies.

Several surveys and studies of contamination levels of inland waters of Latvia, their waters, sediments and biota have indicated generally low contamination levels (low metal concentrations) of waters, river and lake sediments, and of biota (fishes, macroinvertebrates, macrophytes) (Kļaviņš et al., 1995; 1998a; 1998b; 1999; Cimdiņš and Kļaviņš, 1998; Kļaviņš and Briede, 1999). However, raised contamination levels of common pollutants are found in the vicinity of pollution point sources (Kļaviņš et al., 1999).

The general aquatic chemistry of water bodies in Latvia (Figure 2) is influenced by the soil composition, character of vegetation, precipitation, climate, land-use, and human impacts. The combinations of these factors differ for water bodies from different regions. Hydrogencarbonates and calcium dominate among the water ingredients. Increased concentrations of sulphate and magnesium are observed only in several rivers of the Lielupe basin, and elevated chloride and sulphate concentrations may occur in small rivers from coastal areas. Commonly, surface waters of Latvia are rich in organic matter, being highest in rivers of the Lielupe basin and in several small bog rivers. In the Lielupe basin, the high concentrations of nutrients may be explained by intensive agricultural production. The intensive agricultural land-use there also leads to increased soil erosion, which in turn affects water chemistry via the geochemical composition of soils (Figure 2). The largest ranges of concentrations are observed for nutrients, which are released by human activity and are consumed by biological processes (Figure 2). The ranges of concentrations for most inorganic substances are smaller.

Studies of water quality changes in Latvia are particularly important as the recent ongoing changes in the political, economic and social systems have resulted in a sharp decline of industrial and agricultural production (Juhna and Kļaviņš, 2001). The transition processes are associated with a recession in industrial and agricultural production (Figure 3). For example, a substantial reduction of fertilizer use has occurred, along with a decline in the use of manure, pesticides, chemicals in industrial productions and other indicators of the intensity of production. During the economic transition, an environmental protection system has been developed according to traditions in West European countries, and this has acted to further curb the pollution levels. Reduction of the emissions of airborne pollutants (SO_2, NO_x, particulate matter and others (Environmental Indicators in Latvia, 2002) further attest to reduced loading to the environment. Development of new and improved waste and wastewater treatment facilities has resulted in substantial reductions of pollutants to inland waters, as indicated by changes of BOD, COD, N, P emissions (Baltic Environmental Forum, 1999). Several studies have found little or no changes of the actual loading to the Baltic Sea (Tsirkunov et al., 1992; Stålnacke, 1996, Löfgren et al., 1999), however using data of water quality till 1995.

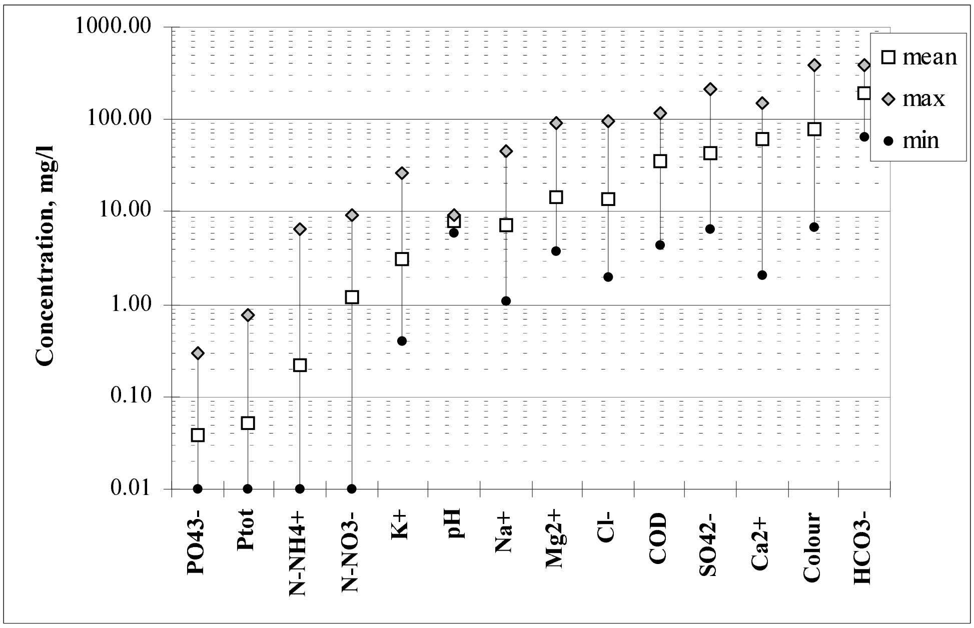


Figure 2 Chemical composition of rivers in Latvia (mean, minimal and maximal values 1977-2002).

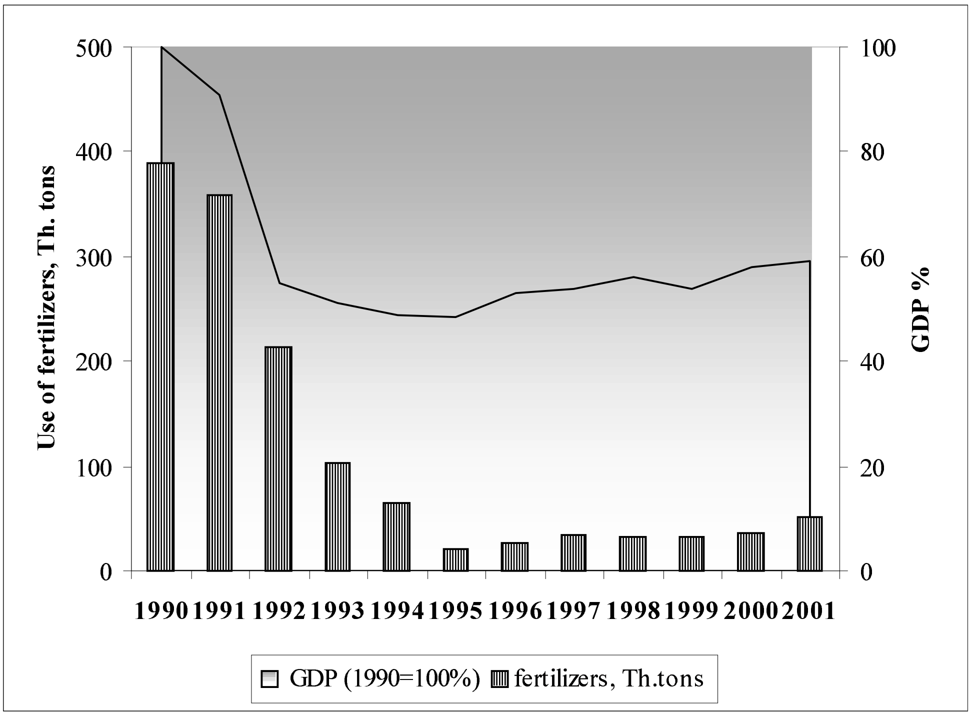


Figure 3 Changes of gross domestic product (GDP) and use of fertilizers in Latvia

Table 1 : Long-term trend (1977-2001) of water quality changes for rivers of Latvia after Man-Kendall test criteria

River	COD	N-NH_4^+	N-NO_3^-	PO_4^{3-}	HCO_3^-	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	Na^+	K^+
Daugava	-0,212	**-2,797**	1,230	**2,226**	1,897	**2,883**	0,016	1,848	**3,555**	-1,821	0,509
Aiviekste	-1,284	**-2,117**	-0,269	1,239	**2,324**	-0,452	**-2,172**	0,491	**2,341**	**-3,000**	-0,744
Gauja	-0,466	**-3,582**	**-2,931**	**-2,713**	**2,256**	**-2,151**	**-4,168**	0,143	1,566	**-3,571**	-1,842
Lielupe	**-2,207**	**-4,097**	-1,830	**-2,717**	**2,657**	0,163	**-2,254**	0,409	1,662	**-2,297**	-0,382
Venta	**-2,441**	**-2,684**	-1,114	0,807	**2,527**	-1,672	-1,878	-0,091	**3,211**	**-2,440**	-0,807
Salaca	-1,328	**-2,262**	**-2,153**	**2,021**	1,189	**2,135**	**-2,072**	1,323	**2,485**	**-2,400**	**-2,190**

One of the main parameters determining long term changes of water chemical composition is water discharge (Figure 4).

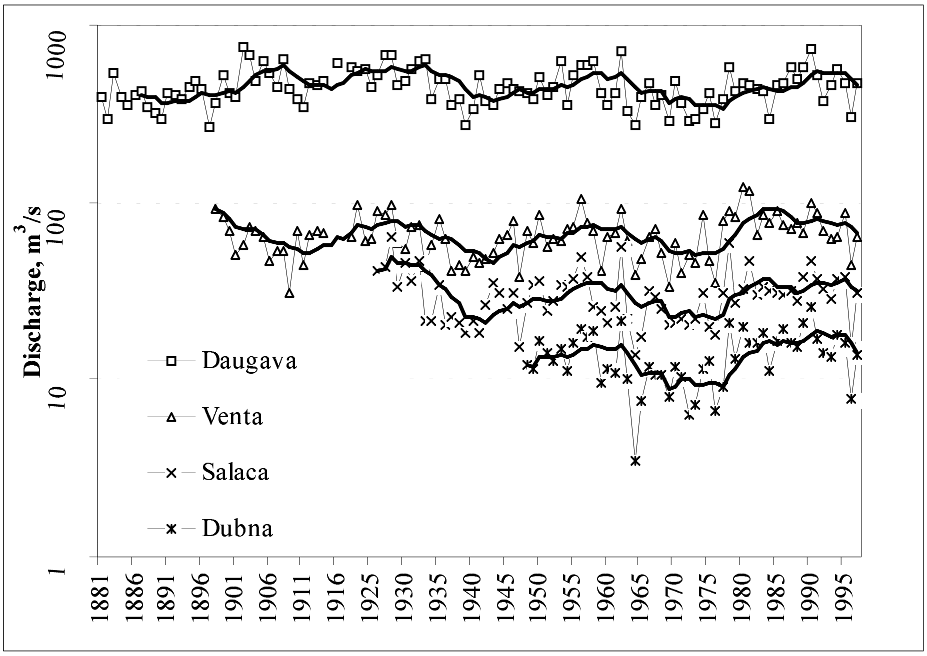
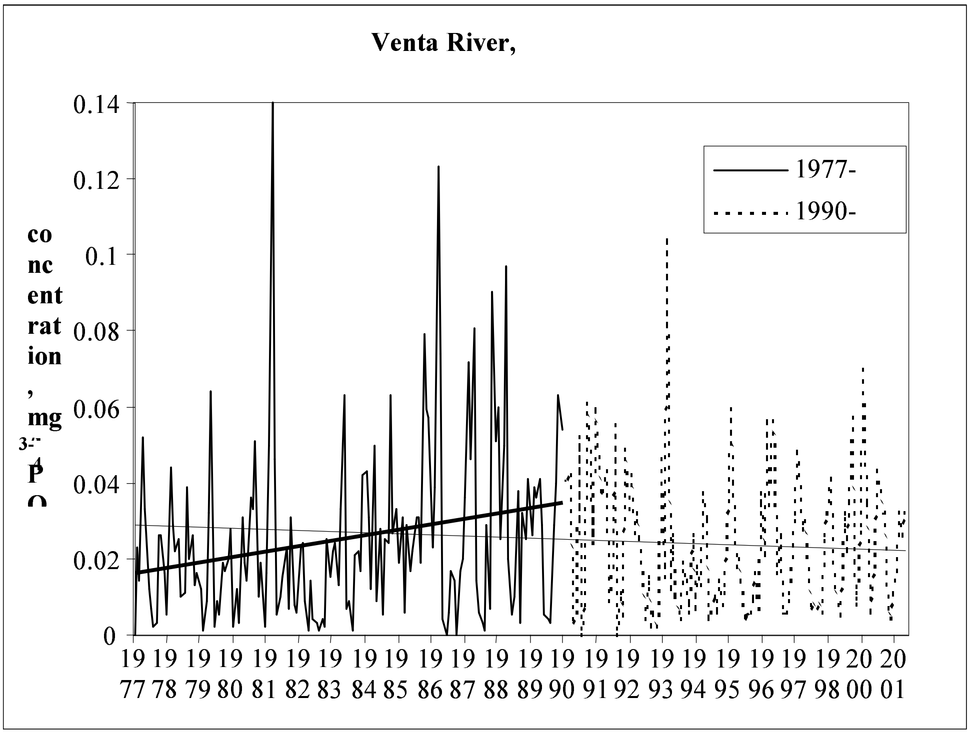


Figure 4. Long-term changes of river discharge in Latvia

Long-term data on water flow do not show reliable trends (Figure 4), but rather reflect processes which influence the hydrologic cycle, such as, solar activity, long-term atmospheric circulation patterns and changes in land-use. During the period of observations the pattern of long-term changes of river runoff can be described as an oscillation in respect to mean values (Klavins et al., 2002). During the period for which regular and reliable observation data of aquatic chemistry are present the water discharge of rivers in eastern Latvia has increased by ~ 10 %, and in the west (Venta, Tebra) by about 40 %. Regardless of the long-term patterns of water discharge, the present water flow regime may be regarded as comparatively increased if compared with centennial mean values for rivers of Latvia. Evidently, the water flow pattern is among the most important factors influencing aquatic chemistry.

For most of the studied substances, trend analysis indicated a monotonous increase or decrease of ingredient concentrations, and their changes may be correctly described as linear trends. Trend analysis of water quality parameters identified increasing trends for magnesium (significant and rising for all rivers) (Figure 5, Table 1), hydrogencarbonate concentrations (increasing for most of rivers), indicating a more active role of carbonate mineral weathering processes. However, it is difficult to relate these weathering trends to human activities except still significant loading due to atmospheric precipitations of sulphur and nitrogen compounds.

Considering the dramatic decrease in agricultural production, the drastic reduction of fertilizer use in the country, and the installation of many new municipal wastewater facilities, different trends are observed for changes of nutrient concentrations. Long-term changes of nutrient concentrations (Figure 5 and Table 1) still commonly can be described as linear trends for the study period. However substantial differences exist for the studied rivers and substances. The concentrations of ammonia are decreasing, and this trend is significant for the largest rivers of Latvia. Changes of nitrate concentrations commonly do not show consistent trend-lines, and decreasing trends are significant for nitrates only in the Gauja and Salaca rivers.



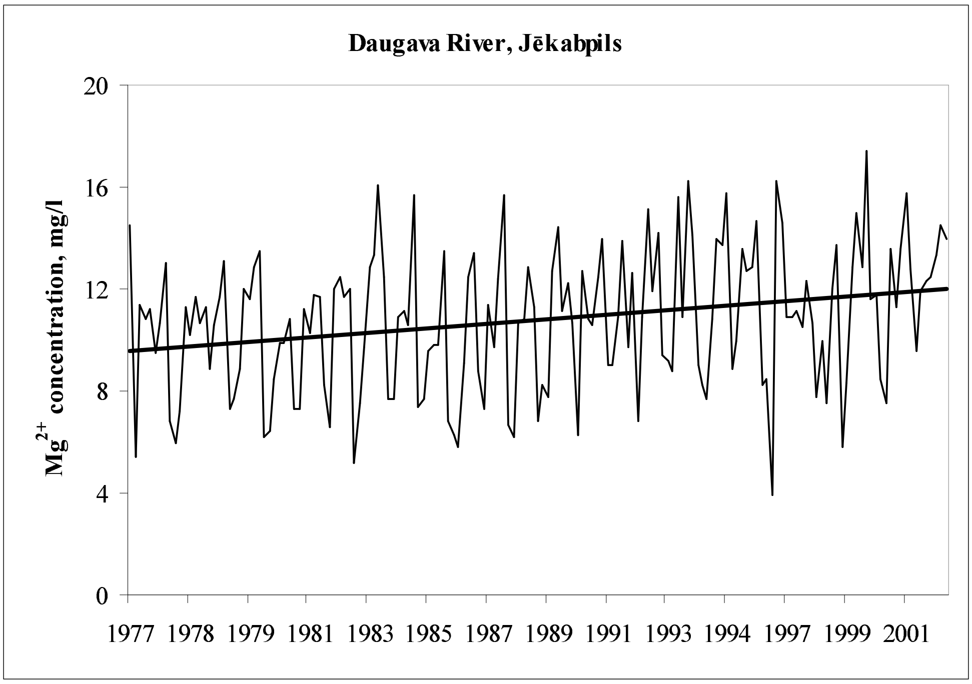


Figure 5. Long-term changes of PO_4^{-3} and Mg^{+2} ions in rivers of Latvia

The failure of the reduction of nitrogen loading to influence directly nitrate concentrations in river waters may be due to slow mineralization of organic nitrogen bound in agricultural and forest soils (Stålnacke, 1996; Löfgren et al., 1999). Also, presently there is still a lack of understanding of nutrient cycling in humus rich soils. Phosphates represent a different situation, as the changes of phosphate concentrations do not reflect simple linear trends. An increasing trend is evident till 1990-1992, followed by a decreased trend (an insignificant increase was found only for the River Salaca which lacks major point sources). Thus, a clear dependence on changes in loading to inland waters is evident: increase till 1991-1993 followed by a gradual decrease after 1992, when recession in industrial and agricultural production began.
The above indicate that basic water chemical composition and its long-term changes largely reflect the intensity of natural processes, such as weathering of soils and minerals, and exchange with mineralized subsurficial waters.

CONCLUSIONS

The study of long-term changes of water quality parameters for the study period indicates changes in intensity of natural geochemical processes and response to changes in human loading. The long-term variability of water chemical composition and the sensitivity of the studied parameters to changes in the environment should be considered in the development of new monitoring programs. The biological qualities of surface waters of Latvia show stable composition with gradually increasing human impact.

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