Long Term Changes of Water Quality in Latvia

Maris Klavins, Valery Rodinov

***Abstract*—**The aim of this study was to analyze long term changes of surface water quality in Latvia, spatial variability of water chemical composition, possible impacts of different pollution sources as well as to analyze the measures to protect national water resources - river basin management. Within this study, the concentrations of major water ingredients and microelements in major rivers and lakes of Latvia have been determined. Metal concentrations in river and lake waters were compared with water chemical composition. The mean concentrations of trace metals in inland waters of Latvia are appreciably lower than the estimated world averages for river waters and close to or lower than background values, unless regional impacts determined by local geochemistry. This may be explained by a comparatively lower level of anthropogenic load. In the same time in several places, direct anthropogenic impacts are evident, regarding influences of point sources both transboundary transport impacts. Also, different processes related to pollution of surface waters in Latvia have been analyzed. At first the analysis of changes and composition of pollutant emissions in Latvia has been realized, and the obtained results were compared with actual composition of atmospheric precipitation and their changes in time.

***Keywords*—**Water quality, trend analysis, pollution, human impact.

I. Introduction

ANALYSIS of long-term changes of aquatic chemistry and river discharge is of importance to study processes in surface waters, but more generally in the environment. Trend analysis of aquatic chemistry is important for decision-making process in area of environmental protection of water quality and to reach aims of river basin management as well as to reduce of loading, at first of nutrients. Further, trend analysis can help to evaluate efficiency of monitoring systems and to support necessary management activities [1]. The different combinations of variable parameters determine the actual concentrations of substances in waters and their long-term and seasonal variability and loading. Of especial importance are studies of changes of nutrient concentrations and loading, considering common eutrophication of coastal waters and inner seas, and in this respect, water composition trends are criteria for evaluation of efficiency of national and international environmental legislation, international agreements [2]. Considering importance of loading regulation, there are many studies dedicated to analysis of factors controlling loading from continent to seas and trend analysis of concentrations of dissolved substances and their loadings to receiving water bodies [3]. Loadings of nutrients and their trends for comparatively short time periods (usually not longer than 5 – 10 years) have been much studied for the Baltic Sea area, considering sensitivity to eutrophication and intensive loading [4], [5]. However, the loading of dissolved substances 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.

In the case of Latvia, it can be possible to link three variables: a) changes of river discharge (dominantly natural process), b) changes of human loading (direct human impact), c) the reaction of water composition (response factor) to identify environmental consequences of these much differing impacts. The reduction of anthropogenic loading was 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 an unprecedented reduction in loads to the environment [6]. The found changes in loading can help to identify the character of responses of water composition and the lag time between input of contaminants in river basins and output of dissolved substances in streams.

The objective of the present study is to study long-term changes of nutrient concentrations in surface waters of Latvia in relation to natural fluctuation and long term changes of river discharge and recent reduction of industrial and agricultural production and associated changes in loading to water bodies.

II. Materials and Methods

The study site covers the entire territory of Latvia (Fig. 1). Latvia is located on the north-western part of East European Plain on the coast of the Baltic Sea. The territory of Latvia occupies 64 000 km^2. Climatic conditions in Latvia can be characterized as humid with mean precipitation ranging from 600 to 850 mm per year [7]. Due to influence of cyclones, summer temperatures are slightly lower, but winter temperatures are higher than the average for temperate zone. The mean temperature in January varies from -2.6 °C to -6.6 °C, and in July from +16.8 °C to +17.6 °C. The rivers in Latvia have mixed water feeding: rain, snowmelt water, and groundwater. The river discharge in spring comprises 45-55 % of the total annual discharge. In winter, only 15-20% of the total annual discharge is formed [7].

Data used in the study were obtained from the Latvian Environment, Geology and Meteorology Centre and Department of Environmental Sciences of the University of Latvia. Monthly records for the whole study period (1980-2015) as well as laboratory reports on the water chemical composition were available. During the study period, the

Maris Klavins. University of Latvia, Riga, Latvia LV 1586 (phone: 371-29479430; e-mail: maris.klavins@lu.lv).
Valery Rodinov, Institute of Biology, Salaspils LV 2169, Latvia (e-mail: roval@email.lubi.edu.lv).

sampling and analytical methods followed standard methods [8]. Changes in the analytical equipment and methods used have occurred during all period of observations; however, intercalibrations have been done. Since 1997, national analytical methods based on ISO standards have begun to be introduced, and for all parameters studied in this article, the results are comparable. Locations of sampling sites and regular monitoring stations are shown on Fig. 1. For trend analysis, data from downstream stations were used. During the study period, the sampling and analytical methods followed standard methods. From 1972 till 1993, water ingredients were analyzed accordingly standard methods used in USSR as summarised in [8]. In 1992-1994, intercalibration programs, at both national and international levels [5], have demonstrated general acceptability of methods used. More or less substantial changes in the analytical equipment and analytical methods used have occurred during all period of observations. In 1997, introduction of national analytical methods based on ISO standards began.

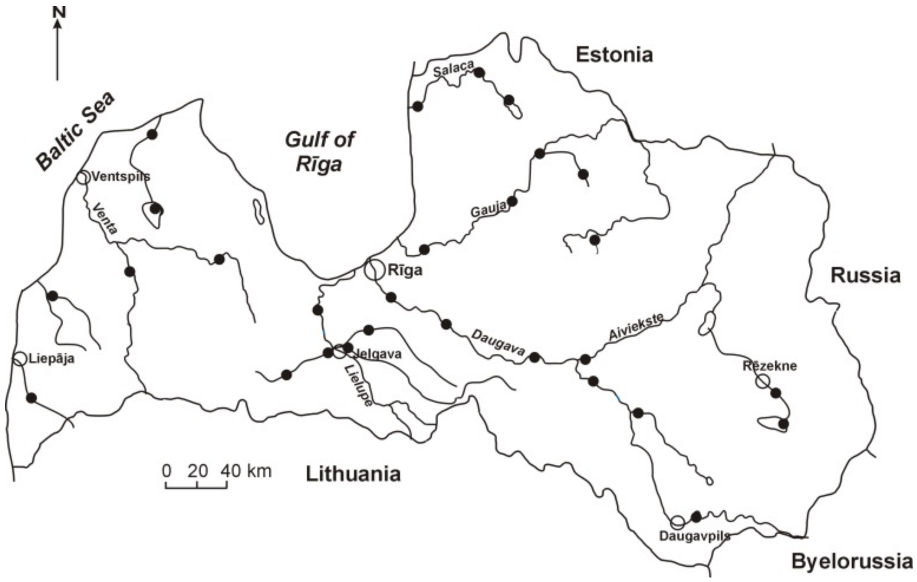

Fig. 1 Study area and river water quality monitoring stations

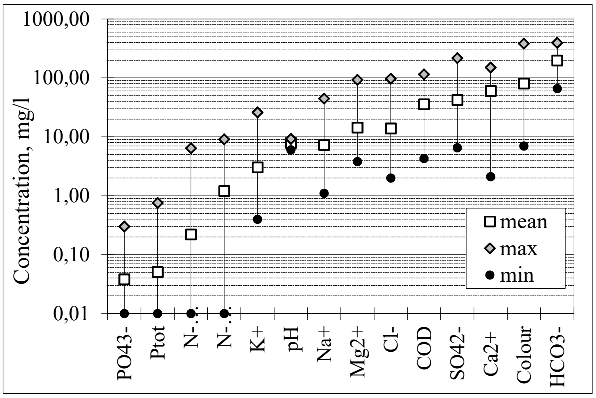

Fig. 2 Chemical composition of studied rivers in Latvia (mean, minimal and maximal values 1980-2015)

The multivariate Mann-Kendall [9] 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. This test can be applied for datasets that have non-normal distribution, missing values or "outliers", serial character (e.g., seasonal changes). Partial Mann-Kendall test was used to detect trends of water quality parameters as it allows including covariates representing natural fluctuations (e.g., water discharge, precipitation) that may affect the studied response variable. The conditional 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 1.65 or less than –1.65.

III. Results and Discussion

The general aquatic chemistry of water bodies in Latvia (Fig. 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. Commonly, surface waters of Latvia are comparatively hard, rich in organic matter, but elevated nutrient concentrations can be observed in the waters of rivers in River Lielupe basin, due to intensive agricultural production. The intensive agricultural land-use there also leads to increased soil erosion, which in turn affects water chemistry (Fig. 2) considering the geochemical composition of soils. The largest ranges of concentrations are observed for nutrients, which are released by human activity and are consumed by biological processes (Fig. 2). The ranges of concentrations for most inorganic substances are smaller.

Several surveys and studies of contamination levels of inland waters of Latvia, their waters, sediments and biota have indicated generally low contamination levels with persistent xenobiotica (PCB, DDT, lindane, heavy metals) of waters, river and lake sediments, and of biota (fishes, macroinvertebrates, macrophytes) [4], [9]. However, raised contamination levels of common pollutants are found in the vicinity of largest cities [9], [10]. 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 [5]. The transition processes are associated with a recession in industrial and agricultural production (Fig. 3). For example, a substantial reduction of fertilizer use has occurred (Fig. 3), 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 to achieve pollution reduction aims.

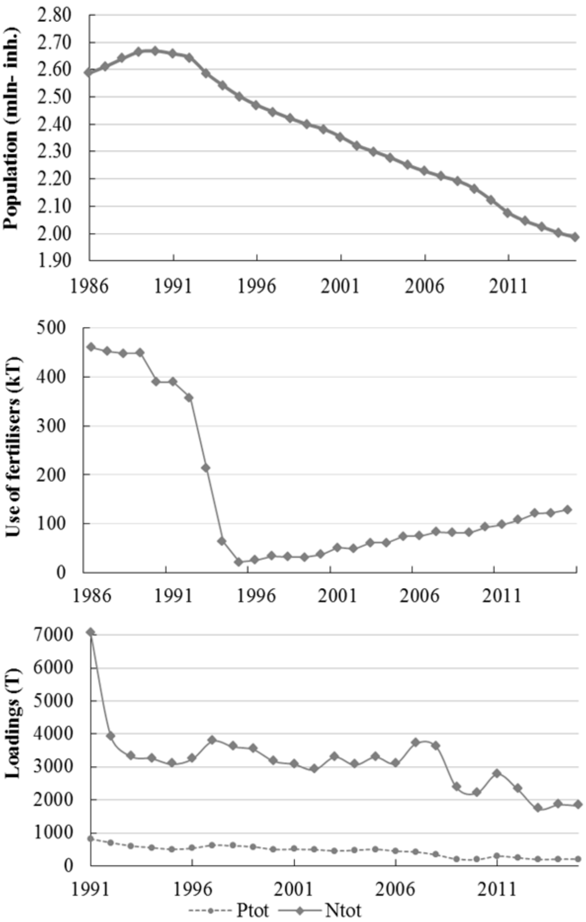

Fig. 3 Changes of population, use of fertilisers, and loading of nitrogen and phosphorus compounds by wastewaters in Latvia during last decades

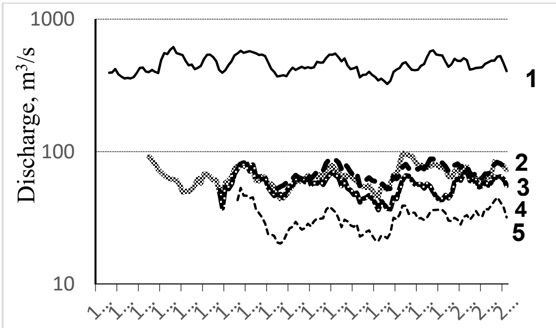

Fig. 4 Long term change of mean annual discharge of the rivers in Latvia Data were smoothed with a 5-year moving average: 1- Daugava; 2- Gauja; 3- Venta; 4- Lielupe; 5- Salaca

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. At the same time, several studies have found little or no changes of the actual loading of dissolved substances to the Baltic Sea [5], however using data of water quality till 1995. Studies of long-term changes are important in the evaluation of the environment. Long-term changes of surface water quality in Latvia have been analysed in several studies, but different groups of substances as well as different data sources have been analysed [5].

Regardless of the long-term patterns of water discharge, the present water flow regime is elevated with respect to average values for last decades for rivers of Latvia. Evidently, the water flow pattern is among the most important factors influencing aquatic chemistry, and recent increase of river discharge determines increase of runoff of dissolved substances.

For most of the studied substances, trend analysis indicated a monotonous increase or decrease of their concentrations, and their changes may be correctly described as linear trends. Trend analysis of water quality parameters identified increasing trends for magnesium (Table I; Fig. 6), hydrogencarbonate, sulphate and calcium 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.

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

Long-term data on water flow do not show reliable trends, for example in the Daugava River (Fig. 4), but rather reflect processes which influence the hydrologic cycle, such as solar activity, long-term atmospheric circulation patterns and changes in land-use. However, the impact of the river hydrological regime on water flow and hence also on water chemical composition is apparent. The river discharge can be described as oscillating process with a frequency of 23 – 30 years [7].

Commonly declining trends of ammonia ion concentrations are characteristic for the whole period of observations and thus cannot be associated with recent reductions of anthropogenic impacts. Hence, it indicates 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. At the same time, trend analysis for changes of nutrient concentrations indicates that the changes in human loading influence the actual concentrations of dissolved substances in waters, as it can be seen on example of River Daugava. Unless there are differences between results obtained using regular the so called conditional Man – Kendall test (trend values are normalized in respect to changes of river discharge), still they are minimal, but the reduction of nutrient concentrations after reduction of their loading is evident.

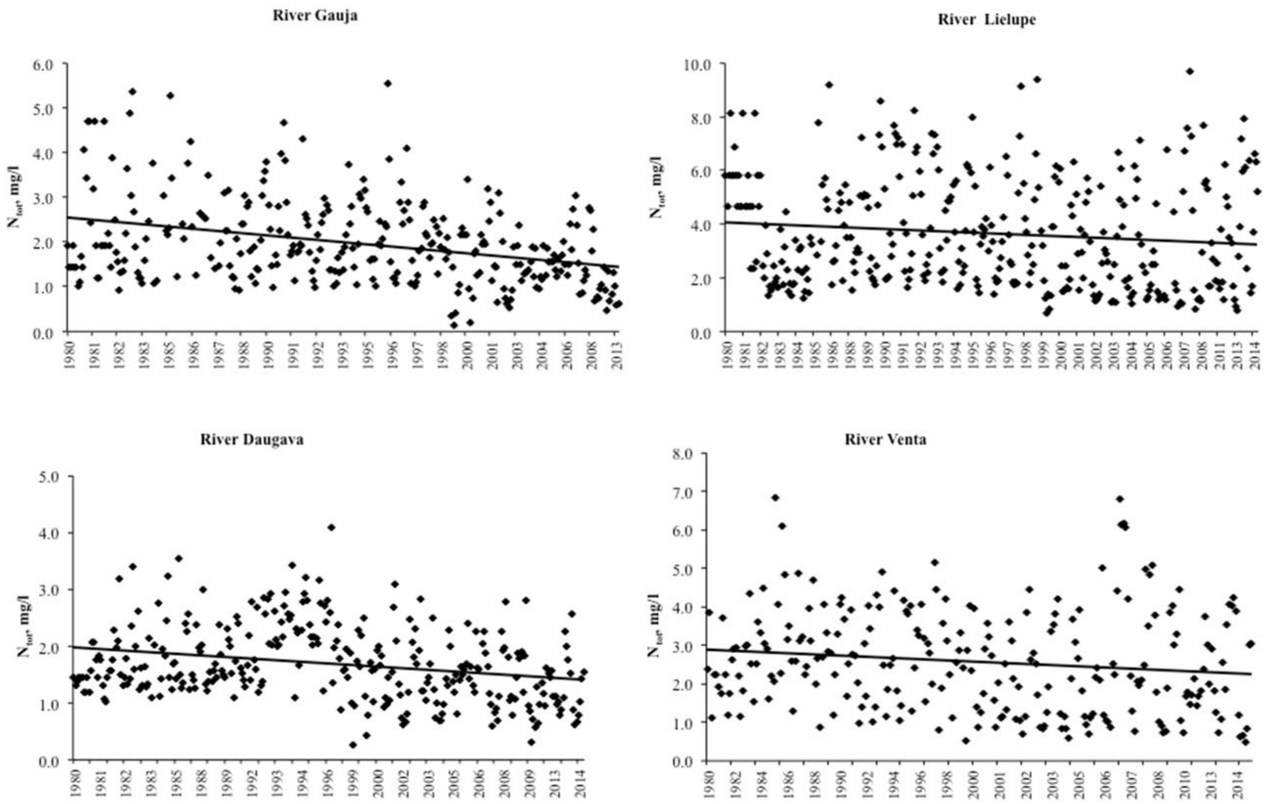

Fig. 5 Long-term changes of N_{total} in waters of rivers Gauja, Lielupe, Daugava and Venta 1980-2015

TABLE I
LONG-TERM TREND (1980-2015) OF WATER QUALITY CHANGES FOR RIVERS OF LATVIA AFTER MAN-KENDALL TEST CRITERIA (IN BOLD – STATISTICALLY SIGNIFICANT VALUES AT 95% LEVEL)

River	Colour	N_{tot}^{+}	P_{tot}	HCO_3^-	SO_4^{2-}	Cl^-
Daugava	3.415	-2.797	2.226	1.897	2.883	0.016
Gauja	1.140	-3.582	-2.713	2.256	-2.151	-4.168
Lielupe	-0.030	-4.097	-2.717	2.657	0.163	-2.254
Venta	-0.732	-2.684	0.807	2.527	-1.672	-1.878
Salaca	0.823	-2.262	2.021	1.189	2.135	-2.072

Long-term changes of nutrient concentrations (Fig. 6 and Table I) 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 Daugava River. 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 [5], [8]. 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.

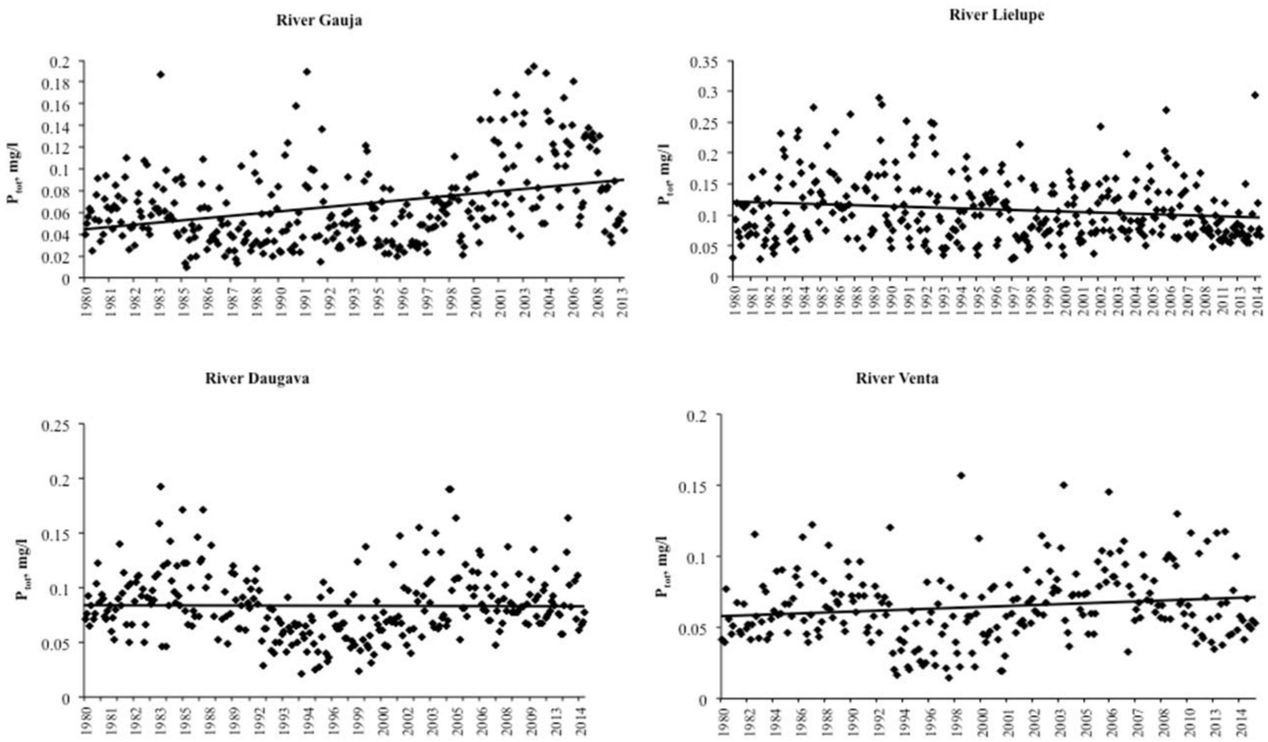

Fig. 6 Long-term changes of P_{total} in waters of rivers Gauja, Lielupe, Daugava and Venta 1980 – 2015

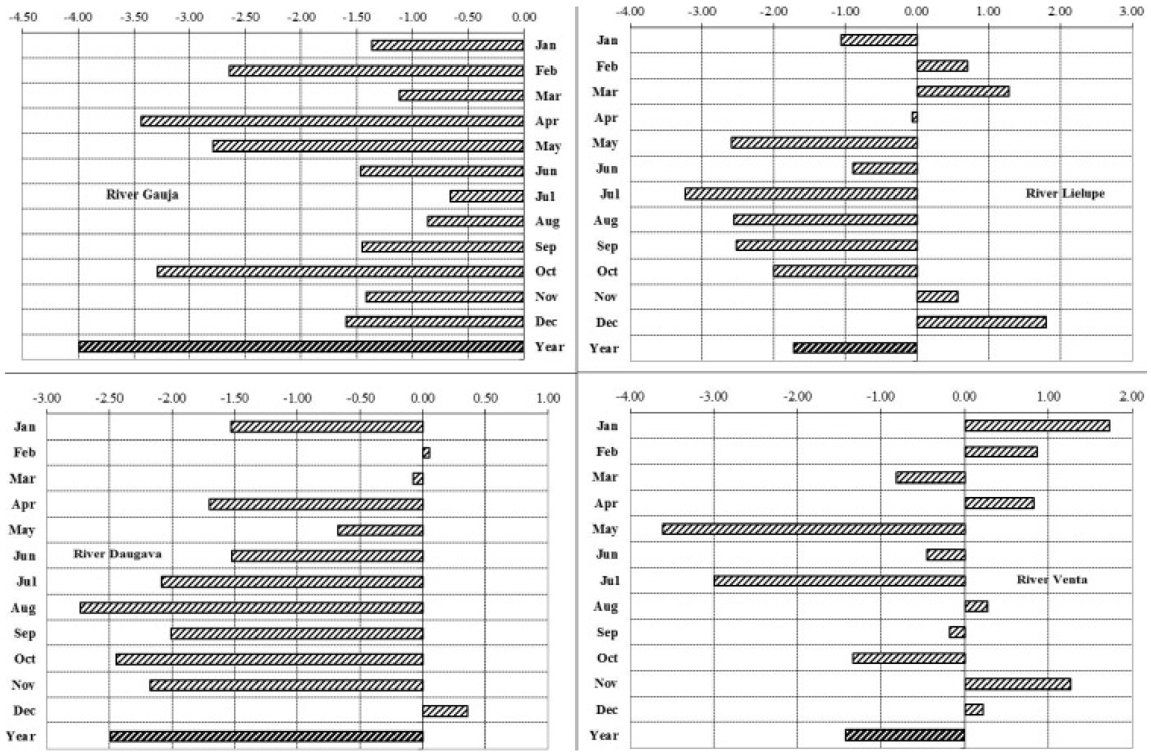

Fig. 7 Trends of long-term seasonal changes of N_{total} in waters of rivers rivers of Latvia (Gauja, Lielupe, Daugava and Venta 1980 – 2015) after Man-Kendall test criteria

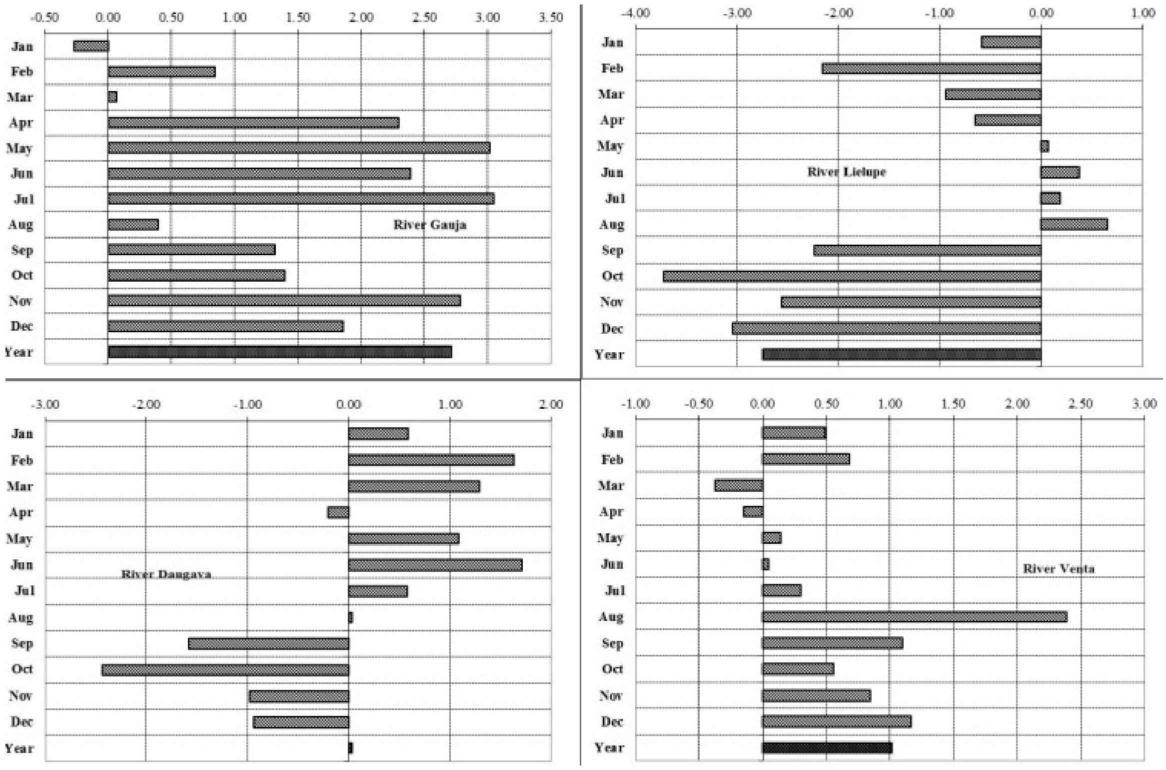

Fig. 8 Trends of long-term seasonal changes of P_{total} in waters of rivers of Latvia (Gauja, Lielupe, Daugava and Venta 1980 – 2015) after Man-Kendall test criteria

IV. Conclusion

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. Among the major driving processes influencing water chemical composition and loading with river waters, long-term variability of river discharge should be considered. 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 monitoring programs and decision-making process.

Acknowledgment

Support from project "Klimata pārmaiņas un dabas resursu ilgtspējīga izmantošana" (Nr. AAP2016/B041) is acknowledged.

References

[1] A. Räike, O. P. Pietilainen, S. Rekolainen, P. Kauppila, H. Pitkanen, J. Niemi, A. Raateland. and J. Vuorenmaa 2003. Trends of phosphorus, nitrogen and chlorophyll a concentrations in Finnish rivers and lakes in 1975 – 2000. *Science of the Total Environment* vol. 310, pp. 47 – 59.

[2] R. Donohue, A.W. Davidson, N.E. Peters, S. Nelson and B. Jakowyna 2001. Trends in total phosphorus and total nitrogen concentrations of tributaries to the Swan-Canning Estuary, 1987 to 1998. *Hydrologic Processes* vol. 15, pp. 2411-2434.

[3] D. F. Brakke, D. H. Landers and Eilers J. M. 1988. Chemical and physical characteristics of lakes in the Northeastern United States. *Environmental Science and Technology* vol. 22(2), pp. 155-163.

[4] K. S. Godwin, S. D. Hafner and Buff M.F. 2003. Long-term trends in sodium and chloride in the Mohawk River, New York: the effect of fifty years of road-salt application. *Environmental Pollution* vol. 124, pp. 273-281.

[5] P. Stålnacke, A. Grimvall, C. Libiseller, M. Laznik M. and Kokorite I. 2003. Trends in nutrient concentrations in Latvian rivers and the response to the dramatic change in agriculture. *Journal of Hydrology* vol. 283, pp. 184-205.

[6] M. Klavins, A. Briede, E. Parele, V. Rodinov. & Klavina I. 1998a. Metal accumulation in sediments and benthic invertebrates in lakes of Latvia. *Chemosphere* vol. 36(15), pp. 3043-3053.

[7] T. Juhna and Klavins M. 2001. Water quality changes in Latvia and Riga. 1980 – 2000: possibilities and constraints. *Ambio* vol. 30, pp. 326-331.

[8] M. Klavins, A. Briede, V. Rodinov, I. Kokorite and Frisk T. 2002. Long-term changes of the river runoff in Latvia. *Boreal Environment Research* vol. 7(4), pp. 447-457.

[9] Standard Methods for the Examination of Water and Wastewater 2012 21th edn, American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC, USA

[10] R. M. Hirsch and Slack J.R. 1984. A nonparametric trend test for seasonal data with serial dependence. *Water Resources Research* vol. 20(6), pp. 727-732.