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TEMPORAL TRENDS IN NITROGEN CONCENTRATIONS IN ESTONIAN RIVERS

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Abstract. The nutrient content in streams and rivers depend on many interacting processes such as hydro-geographical conditions and land use practices. The aim of this study was to investigate the current status of Estonian rivers and determine any trends in the concentrations of total nitrogen (TN) and nitrate-nitrogen (NO_3-N) between 1992 and 2013. This study involved 43 monitoring sites and 32 rivers in Estonia. The temporal trends were assessed using the partial Mann-Kendall (PMK) test, which was adapted to account for the influence of water discharge. Most of the studied streams and sites did not show any trend in nitrogen concentrations. The statistically significant downward trend in TN was identified at 13 monitoring stations and upward trend at four monitoring sites. The results for NO_3-N showed a statistically significant downward trend at three sampling sites while the upward trend was found at nine monitoring stations, particularly at four sites located within the nitrate vulnerable zone (NVZ). Overall, the increasing nitrate content in surface waters can most probably be attributed to the intensification of agricultural activities in rivers catchments during the last ten years. However, there are still many uncertainties in nutrient loss processes. Thus, the national monitoring programmes should be further developed.

Keywords: *Mann-Kendall, monitoring, nitrate-nitrogen, total nitrogen, trend analysis, water quality.*

Introduction

During the past decades, significant efforts have been made to reduce eutrophication of the Baltic Sea. Recently, all the Baltic Sea countries and European Community (EC) adopted the newly formulated Baltic Sea Action Plan (BSAP) to reduce the anthropogenic nutrient load and restore a good ecological status of the Baltic Sea by 2021 (HELCOM, 2007). Accordingly, country-wise annual nutrient input reduction targets were proposed to achieve this objective. The EC Water Framework Directive (EC, 2000) aims at achieving at least good status for almost all the water bodies in the coming years. Moreover, the EC Nitrate Directive (EC, 1991) provides a framework to (a) control the loss of nitrogen from the agricultural sources, (b) analyse the requirements for monitoring and assessment of trends, and (c) check the efficiency of measures applied to reduce the nitrate content in surface and groundwater as well as the coastal sea. The objectives of the European Directives and international conventions are reflected in the Estonian national regulations, particularly in the Estonian Environmental Strategy, 2030. To meet all the requirements laid down in BSAP, the EU Directives and national regulations need to have a proper understanding of the trends and drivers responsible for changing the nutrient´s content in surface waters and pollution load on the sea.

Significant changes in economic and social structures have taken place in Estonia since the late 1980s and early 1990s, resulting in improved wastewater treatment and lower intensity of agriculture (Iital *et al.*, 2010). Thus, the improved performance of wastewater treatment plants in Estonia, especially in large cities, have resulted in more than 70% decrease in nitrogen and phosphorus point load on the recipient water bodies in 2007 as compared to 1992 (Pachel *et al.*, 2012). In the agricultural sector, the use of inorganic fertilisers has dropped significantly, and in 2005 its amount constituted of only about 13% of the peak reached in 1987–1988 (Statistics Estonia, 2006). The total area of arable land (crop field and cultural grassland) also rapidly decreased, and in 2001, it constituted of around 60% of the arable land in the early 1990s (Statistics Estonia, 2002). During the same period, the number of livestock units (LU) decreased by more than 60%, from 1,205,000 LU in 1990 to 442,780 LU in 2001 (Statistics Estonia, 2002). However, the revitalisation of agriculture and centralisation of the agricultural land into large holdings has been observed in Estonia over the last decade. The total agricultural area (arable land, pasture, agricultural land temporarily not being used) has increased from 875,800 ha in 2001 (Statistics Estonia, 2002) to 966,000 ha in 2013 (Statistics Estonia, 2014a). Currently, almost 90% of the agricultural land is in use. The application of mineral nitrogen fertilisers has also increased from 74 kg/ha in 2001 (Statistics Estonia, 2004) to 86 kg/ha of fertilised arable land area in 2013 (Statistics Estonia, 2014b). The number of LU has not changed significantly in the recent years, and there were 432,624 LU in 2013.

In Estonia, the national water quality monitoring programme was revised in the beginning of 1990s to systematically collect long-term data on nutrient concentrations in Estonian waters and provide this information to the authorities and all other interested stakeholders so that they can devise suitable measures to control the loss of nutrients in surface and ground water bodies. According to the obtained results, agriculture proved to be a major source of water quality-related problems in Estonia. In order to protect the surface and ground waters from agricultural pollution, a nitrate vulnerable zone (NVZ) was designated in Pandivere and Adavere-Põltsamaa areas in 2003. The NVZ forms only 7.5% of the Estonian territory but is characterised by more intensive agriculture compared to the other parts of the country, widely spread karst phenomena and particularly a thin Quaternary sediment cover (Keskkonnaagentuur, 2014a). Over the past two decades, the quality of NVZ surface and ground waters have varied significantly (Keskkonnaagentuur, 2014a). A recent report (Keskkonnaministeerium, 2012) on the implementation of the EC Nitrates Directive in Estonia revealed increasing trend of nitrogen in some rivers whose catchments are fully or partly placed within the NVZ. These increasing trends have been mainly explained by elevated runoff, although the consumption of fertilisers between the two reporting periods (2004–2007 and 2008–2011) in the NVZ counties have indicated increasing tendency. In 2008–11, the use of nitrogen fertilisers increased by 1.4 times in three NVZ counties as compared to the mean level in 2004–2007. The yields of cereals in the NVZ counties acted as an indicator of more balanced use of nutrients and also increased by about 20% between the periods 2004–2007 and 2008–2011.

Many studies have shown that nutrient concentrations in streams and rivers depend on different interacting processes including hydro-geographical conditions and land use practices (Arheimer, Liden, 2000; Bechman, Stålnacke, 2005). In agriculture dominated catchments and streams, the level of fertilisers application, the proportion of cultivated land, agricultural management practices, soil type, and crop species could act as factors that determine nutrient concentrations. However, according to Iital *et al.* (2010), there still exist many knowledge gaps in nutrient loss processes, making it difficult to draw direct relationships between changed land-use practices and water quality. The time-lag between gross emission changes and stream water quality can also prove to be remarkable. In order to set a clear distinction, the present study was conducted taking into account the long-term patterns with more recent monitoring data. Thus, the study aimed at investigating the current status of Estonian rivers and determining any trends in nitrate-nitrogen (NO_3-N) and total nitrogen (TN) concentration in river waters between 1992 and 2013. Another aim of the study was to investigate the possible relationships between these recent changes in water quality and land use or hydrological conditions. Such country-based analysis is important to determine the major factors influencing the trends in nitrogen concentration and developing realistic management practices that can improve the water quality in the Estonian rivers.

Materials and Methods

Study area

All the watersheds of Estonia (45,227 km^2) drain into the Baltic Sea. The Estonian climate and vegetation are characteristic of the temperate zone; however, the closeness to the sea causes certain differences between the coastal and inland areas. The mean air temperature in January varies from −6 to −7 °C in Central and East Estonia and −2 to −4 °C in the Western part of the country. The average air temperature (16–7 °C) in July is more homogeneous throughout the country. The mean annual precipitation is about 661 mm (Tarand *et al.*, 2013) that exceed the long-term evaporation, which is around 460 mm. The snow cover during winter varies considerably amongst the country's regions and lasts on an average for 75–135 days. The topography of the country is mostly flat with some uplands of about 75–100 m above the sea level. The soils of Estonia are characterised by high diversity due to different composition of parent material and diverse water conditions, a large share of peat land and peaty soils (about half), plenty of calcareous soils and the high content of rocks (FAO, 2006). The brown typical and lessive soils are the most productive agricultural soils in Estonia and are mainly distributed in Central part of the country and Pandivere Uplands including the NVZ areas. Slightly over 50% of the land is covered by forests, and the agricultural land constitutes approximately 31% of the land area available (Keskkonnaagentuur, 2014b).

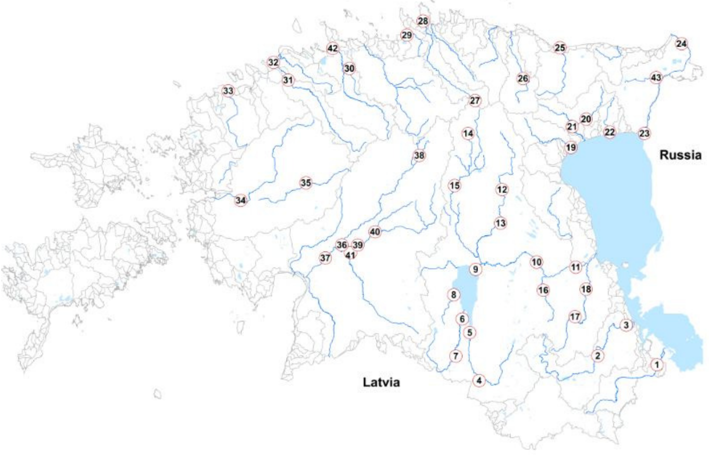


Fig. 1. The location of sampling sites

The present study covers almost the entire territory of Estonian mainland and is based on the long-term (1992–2013) monitoring data series from 43 sampling sites and 32 rivers that have a catchment size ranging from 34,8 km^2 (Preedi-Varangu) to 56,060 km^2 (Narva-Narva) (Fig. 1, Table 1). The proportion of agricultural land in catchments varies from 8% in Mustajõgi-Mustajõe to 67% in Valgejõgi-Porkuni. At present, nearly 60% of all agricultural land in Estonia is used as sown area of the field crops, of which more than half (53%) is under cereals, 28% is used for the production of forage crops, 15% is under industrial crops and the rest 4% is used for vegetables, potatoes and legumes production (Statistics Estonia, 2014a).

Table 1. The main characteristics of the analysed catchments

Site	River-sampling site	Catchment	Land type					
No.		area, km^2	Agricultural, %	Cropped land, %	Forest, %	Wetland, %	Artificial, %	Water, %
1	Piusa-Korela	733	46	22	52	0.5	0.6	0.1
2	Võhandu-Himmiste	848	48	23	47	0.6	2.5	1.6
3	Võhandu-Räpina	1144	48	23	47	1.3	2.4	1.4
4	Väike-Emajõgi-Tõlliste	1054	50	29	47	0.3	2.1	1.0
5	Väike-Emajõgi-Pikasilla	1270	45	26	52	0.4	1.8	0.8
6	Õhne-Suislepa	557	39	23	56	2.8	1.2	0.9
7	Õhne-Roobe	266	27	15	67	4.2	0.3	1.8
8	Tarvastu-Põdraoja	108	56	37	42	0.0	1.5	0.0
9	Emajõgi-Jõesuu	3374	42	26	47	1.7	1.2	8.4
10	Emajõgi-Tartu	7828	42	28	50	2.8	1.5	4.0
11	Emajõgi-Kavastu	8539	43	28	49	2.7	1.8	3.7
12	Pedja-Jõgeva	665	35	26	62	2.2	1.0	0.0
13	Pedja-Tõrve	776	36	27	60	2.0	1.7	0.1
14	Preedi-Varangu	34.8	56	44	43	0.0	0.9	0.0
15	Põltsamaa-Rutikvere	861	42	33	52	3.4	1.9	0.4
16	Porijõgi-Reola	241	55	27	44	0.0	0.3	0.4
17	Ahja-Kiidjärve	336	52	29	47	0.0	0.5	0.1
18	Ahja-Lääniste	930	51	30	47	1.0	0.9	0.2
19	Avijõgi-Mulgi	366	27	19	72	0.1	0.8	0.0
20	Rannapungerja-Roostoja	214	15	6	77	6.5	1.3	0.1
21	Tagajõgi-Tudulinna	252	10	2	85	5.1	0.2	0.1
22	Alajõgi-Alajõe	140	15	6	83	1.3	0.3	0.2
23	Narva-Vasknarva	14639*	40	24	53	3.3	1.5	2.4**
24	Narva-Narva	15527*	38	23	54	3.7	1.9	2.7**
25	Purtse-mouth	810	24	15	66	5.3	4.8	0.1
26	Kunda-Lavi	362	28	20	69	2.9	0.1	0.1
27	Valgejõgi-Porkuni	57	67	53	31	0.0	1.2	0.7
28	Valgejõgi-Loksa	453	29	20	62	5.2	3.3	0.4
29	Pudisoo-Pudisoo	132	20	10	75	3.4	1.4	0.0
30	Leivajõgi-Pajupea	96	37	21	60	2.8	0.4	0.0
31	Keila-Keila	635	45	27	47	5.6	2.3	0.0
32	Keila-mouth	682	47	28	45	5.3	3.0	0.0
33	Vihterpalu-Vihterpalu	474	17	10	72	10.6	0.4	0.0
34	Kasari-Kasari	2640	34	24	61	4.3	0.8	0.1
35	Velise-Valgu	135	21	13	74	4.9	0.0	0.0
36	Pärnu-Tahkuse	2077	38	29	56	4.0	1.7	0.0
37	Pärnu-Oore	5154	36	25	58	4.5	1.5	0.1
38	Vodja-Vodja	52	59	46	35	4.6	1.2	0.0
39	Navesti-Aesoo	1008	36	26	58	5.2	1.1	0.0
40	Saarjõgi-Kaansoo	184	22	16	77	1.3	0.0	0.0
41	Halliste-Riisa	1884	34	20	60	4.3	1.5	0.3
42	Pirita-Lükati	794	37	21	56	3.0	2.9	0.7
43	Mustajõgi-Mustajõe	389	8	4	74	10.2	7.0	0.6

* Estonian part of the catchment

** Does not include Lake Peipsi

Data sources and sampling strategy

The water quality data was obtained from the national environmental monitoring data bank. The sampling frequency of grab samples amongst the monitoring sites was quite different, thus varying from monthly time resolution to 3–4 samples per year (Table 2). The sampling frequency was constant at only 19 monitoring sites, and the samples were taken every month or once every two months. In another 21 cases, the sampling frequency had decreased during the monitoring period, particularly after 2006. It is possible that decreased sampling frequency could affect the trends in TN and NO_3-N in these rivers, although this interrelation was not directly investigated. On the contrary, at three sampling sites (Ahja-Kiidjärve, Pudisoo-Pudisoo and Vihterpalu-Vihterpalu), the monitoring frequency had increased from 6 to 12 per year. The flow data for all studied water quality stations was gained from the Estonian Meteorological and Hydrological Institute (EMHI). The river flow was not always measured at the same point where the water-quality information was collected. Therefore, specific runoff of the catchment was used to recalculate stream flow at the point from where the water samples were taken. Analysis of the water samples was carried out in Estonian accredited laboratories using standardised methods such as ISO 11905-1 for TN and ISO 10304-1, ISO 7890-3, or ISO 13395 for NO_3-N. The land-cover data was taken from the updated CORINE Land Cover (CLC) maps (reference year: 2006). According to the CLC data, the land use was classified into six categories: agricultural land, forest lands, wetland, artificial land and water. Specific information concerning agricultural practices and the type of crops being grown in the studied catchments was taken from the Estonian Agricultural Registers and Information Board (PRIA). Information on fertilisers application and number of livestock within the Estonian counties was taken from the Statistical Office of Estonia. It was assumed that the county data will be representative for river catchments that are mostly located within the county borders. The information on soil type was gained from the Estonian Land Board.

Statistical methods

In the present study, a modified version of the classical Mann-Kendall (Mann, 1945; Kendall, 1975) test, referred to as the partial Mann-Kendall test (PMK), was carried out to identify the trends in NO_3-N and TN concentrations in surface waters. This statistical non-parametric method is widely used to detect the monotone trends in hydrological, climatic, water quality, and other natural time series (Hirsch *et al.*, 1982; Hipel *et al.*, 1988; Onoz, Bayazit, 2003). While assessing the water quality data, hydro-meteorological conditions can lead to natural fluctuation in the nutrient concentration time series and impede the detection of a human-induced trend (Stålnacke, Grimvall, 2001, Stålnacke *et al.*, 2014). In order to deal with the influence of such fluctuations, it is important to include some explanatory variables (e.g., meteorological or hydrological). In our case, the water discharge (Q) was included in the analyses as such a variable.

Results and discussions

In the present study, the PMK test revealed statistically significant (P-value < 0.05; two-sided test) downward trend in TN at 13 monitoring stations and upward trend at 4 sampling sites (Table 2). Thus, most of the studied streams and sites did not show any trend in TN. The downward trend in TN was observed mainly in southern and south-eastern part of the country, both in catchments with relatively high share (40–50%) of agricultural land (Võhandu, Tarvastu, Väike-Emajõgi-Tõlliste) as well as in areas dominated by forest lands (Tagajõgi, Alajõgi, Õhne-Roobe, Rannapungerja). These findings were confirmed by the results of the earlier studies covering 53 Estonian sampling sites on 40 rivers and streams for the period 1992–2006 (Iital *et al.*, 2010) in which statistically significant downward trends in TN were found at 18 sampling sites. The results of other investigation conducted in Estonia for period 1986–2001 (Iital *et al.*, 2005) indicated downward trends in TN concentration in 20 out of 22 sites in the Lake Peipsi drainage basin. Such rapid decline in TN concentrations in many Estonian rivers as a response to changed agricultural practices is somewhat surprising. With similar hydro-meteorological conditions as that of Estonia, Latvia has also experienced significant decrease in the application of fertilisers at the beginning of the 1990s, resulting in limited response of nitrogen concentrations in Latvian rivers (Stålnacke *et al.*, 2003). Amongst the Lithuanian rivers, only one of the seven sites studied showed a statistically significant downward trend in the TN and one in the NO_3-N data for the period 1991–2000 (Povilaitis, 2006). For the case of large Nemunas River in Lithuania, Sileika *et al.* (2006) reported even a continuous strong increase of nitrate concentration in the surface water, probably due to a large storage and accumulation of soil nitrogen before the 1990s.

The downward trend for TN in the rivers Tagajõgi and Alajõgi might be explained by large tracts of forest areas (85% and 83%, respectively) in the catchment and insufficient maintenance of the drainage ditches during the last decades that led to the overgrowth of bushes and microphytes, which in turn enhanced denitrification and biological uptake (Iital *et al.*, 2005, Iital *et al.*, 2010). The share of peaty soils in these catchments varies from 18 to 39%, and more than 40% of these soils represent fens that are commonly drained. The share of NO_3-N in TN in the catchments of rivers Tagajõgi and Alajõgi are rather low (28% and 24% respectively). The nitrate concentration and runoff often increases with drainage improvements (Skaggs *et al.*, 1994); however, it diminishes over time in conditions when the drainage systems are not well maintained. Poorly drained soils and elevated water table could contribute to the lower nitrogen content and losses resulting due to enhanced denitrification (Gambrell *et al.*, 1975).

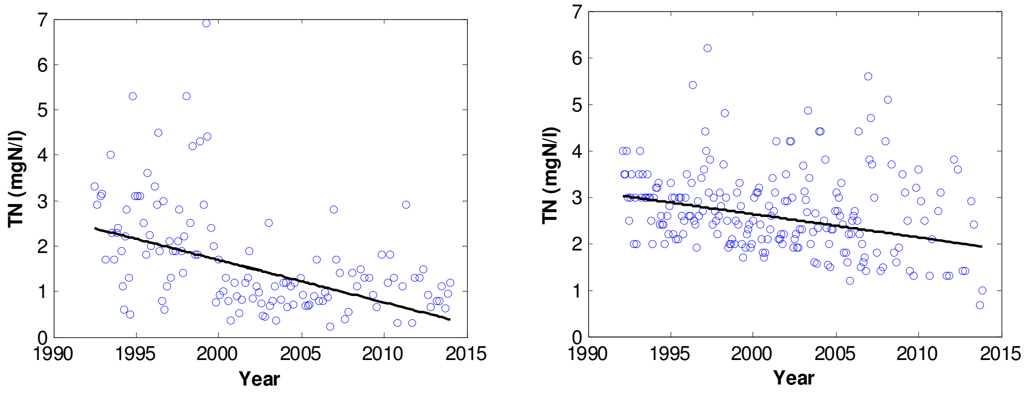
Table 2. PMK-stat and long-term trends for total nitrogen (TN) and nitrate-N (NO_3-N) in Estonian rivers

Site	River-sampling site	Years	Samples	Total N		Nitrate-N	
No.		monitored	per year	PMK-stat	*P*-value*	PMK-stat	*P*-value*
1	Piusa-Korela	1992–2013	12	-2.16	**0.031**	0.24	0.809
2	Võhandu-Himmiste	1992–2013	6 (4)	-3.07	**0.002**	1.54	0.123
3	Võhandu-Räpina	1992–2013	12	-2.42	**0.016**	1.75	0.081
4	Väike-Emajõgi-Tõlliste	1992–2013	12 (6)	-3.21	**0.001**	0.35	0.724
5	Väike-Emajõgi-Pikasilla	1993–2013	12 (6)	-2.76	**0.006**	-0.21	0.831
6	Õhne-Suislepa	1992–2013	12 (6)	-2.48	**0.013**	-0.44	0.657
7	Õhne-Roobe	1992–2013	6	-2.12	**0.034**	-1.30	0.193
8	Tarvastu-Põdraoja	1992–2013	12 (6, 4)	-3.92	**< 0.001**	-0.84	0.403
9	Emajõgi-Jõesuu	1992–2013	12 (6)	0.30	0.767	0.37	0.713
10	Emajõgi-Tartu	1992–2013	12 (6, 4)	0.72	0.474	1.43	0.152
11	Emajõgi-Kavastu	1992–2013	12	-0.05	0.959	1.85	0.065
12	Pedja-Jõgeva	1992–2013	6	1.32	0.187	2.76	**0.006**
13	Pedja-Tõrve	1992–2013	6 (4)	1.21	0.225	2.47	**0.014**
14	Preedi-Varangu	1992–2013	6 (12, 4)	-0.67	0.503	0.94	0.345
15	Põltsamaa-Rutikvere	1992–2013	6	0.11	0.913	2.04	**0.042**
16	Porijõgi-Reola	1992–2013	12 (6)	-1.29	0.199	2.15	**0.031**
17	Ahja-Kiidjärve	1992–2013	6 (12)	-1.47	0.142	2.68	**0.007**
18	Ahja-Lääniste	1992–2013	12 (6)	-0.97	0.334	3.08	**0.002**
19	Avijõgi-Mulgi	1992–2013	12	-1.41	0.159	2.89	**0.004**
20	Rannapungerja-Roostoja	1992–2010	12	-2.88	**0.004**	-0.83	0.407
21	Tagajõgi-Tudulinna	1992–2013	8 (6, 4)	-3.19	**0.001**	-2.97	**0.003**
22	Alajõgi-Alajõe	1992–2013	12	-3.27	**0.001**	-1.86	0.063
23	Narva-Vasknarva	1992–2013	12	0.96	0.335	0.53	0.596
24	Narva-Narva	1992–2013	12	2.07	**0.039**	0.17	0.869
25	Purtse-mouth	1992–2013	12	-3.63	**< 0.001**	-0.47	0.637
26	Kunda-Lavi	1992–2013	6-7 (4)	-3.56	**< 0.001**	-3.46	**0.001**
27	Valgejõgi-Porkuni	1992–2013	6	-1.02	0.306	-0.80	0.424
28	Valgejõgi-Loksa	1992–2013	12	0.27	0.785	0.68	0.498
29	Pudisoo-Pudisoo	1992–2013	6 (12)	1.10	0.273	0.94	0.347
30	Leivajõgi-Pajupea	1992–2013	12 (6)	2.22	**0.026**	1.96	0.051
31	Keila-Keila	1992–2013	6	0.53	0.595	0.01	0.995
32	Keila-mouth	1992–2013	12	-0.53	0.593	-1.13	0.259
33	Vihterpalu-Vihterpalu	1992–2013	6 (12)	1.59	0.113	1.39	0.166
34	Kasari-Kasari	1992–2013	12	1.50	0.134	1.05	0.296
35	Velise-Valgu	1992–2013	12 (4, 6)	-1.27	0.205	-2.42	**0.016**
36	Pärnu-Tahkuse	1992–2013	6 (12, 4)	1.92	0.055	2.51	**0.012**
37	Pärnu-Oore	1992–2013	12	1.74	0.081	2.93	**0.003**
38	Vodja-Vodja	1992–2013	6 (4)	1.15	0.252	1.07	0.287
39	Navesti-Aesoo	1992–2013	6 (4)	1.20	0.231	-0.09	0.928
40	Saarjõgi-Kaansoo	1992–2013	6 (4)	2.52	**0.012**	1.70	0.089
41	Halliste-Riisa	1992–2013	6 (4)	2.23	**0.026**	-0.80	0.425
42	Pirita-Lükati	1997–2013	12	-0.23	0.818	-0.54	0.59
43	Mustajõgi-Mustajõe	2001–2013	12 (4)	1.74	0.083	0.81	0.421

*Statistically significant trends (*P*-value < 0.05; two-sided test) are marked in bold

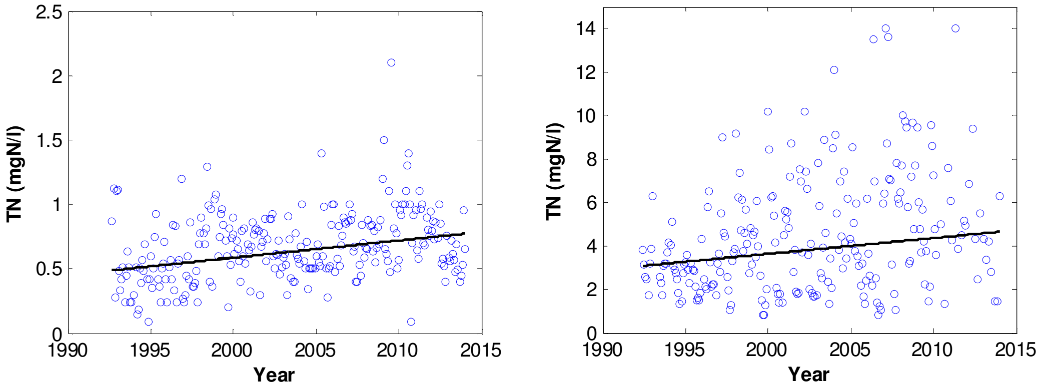
The statistically significant upward trend for TN in the Narva-Narva, Leivajõgi-Pajupea, Saarjõgi-Kaansoo and Halliste-Riisa monitoring sites (Fig. 2) did not appear in the similar analysis made over the period of 1992–2006

(Iital *et al.*, 2010), although an increasing tendency has been detected, except for the river Narva. The catchment properties as well as the types of land use activities of these sites are different. Therefore, these upward trends cannot be explained by a single factor alone. Particularly, statistically significant increasing TN trend at the Narva-Narva station is difficult to explain. The water quality of the river Narva is largely determined by the water quality of Lake Peipsi. The nitrogen content in the river at the Narva-Narva site is rather low (mean concentrations during monitoring period is 0.67 mg N/l) and comparable with the mean TN levels in the lake that is below 1 mg N/l. Nitrogen concentrations in the lake (Keskkonnaagentuur, 2015) as well as at the Narva-Vasknarva site do not show any statistically significant upward trend. The trends in TN concentrations in rivers discharging into the lake are even negative in most of the cases. The mean content of TN in the rivers Halliste and Saarjõgi is rather low (e.g. 1.6 and 1.3 mg N/l, respectively) as compared to the river Leivajõgi where it accounts to 4.4 mg N/l. The formation of NO_3-N is less than 50% in the rivers Halliste and Saarjõgi while it is higher (67%) in the river Leivajõgi. The share of arable land in the catchments of Leivajõgi, Saarjõgi and Halliste does not exceed 20% (Table 1). Peaty soils in the catchments of Saarjõgi, Halliste and Leivajõgi form 19, 23 and 53%, of the total soil content respectively. The upward trends in these rivers can be attributed to the rather high content of humic substances from the wetland areas. The results obtained while monitoring the small catchments in Estonia with a high share of drained fens indicated that the TN concentrations often exceed 5 mg/l. The rising trend of TN has been accompanied by the upward trend of water colour and chemical oxygen demand (COD) during the monitoring period.



Tagajõgi-Tudulinna

Tarvastu-Põdraoja

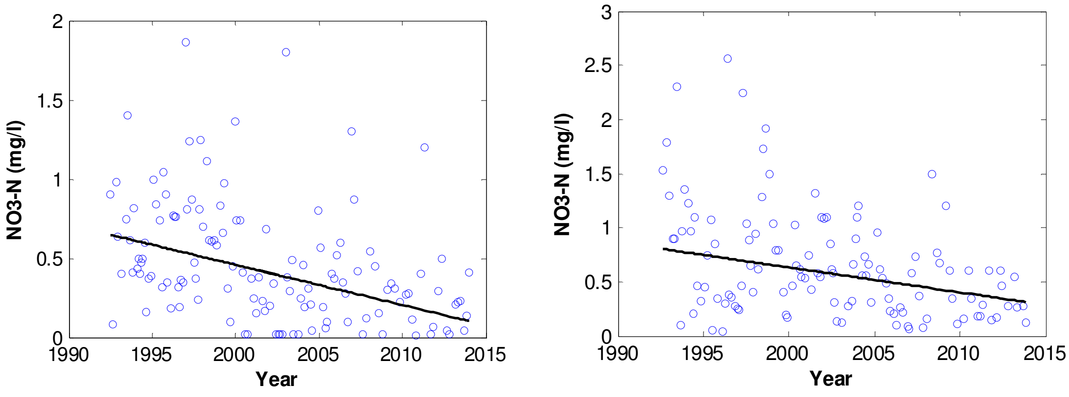


Narva-Narva

Leivajõgi-Pajupea

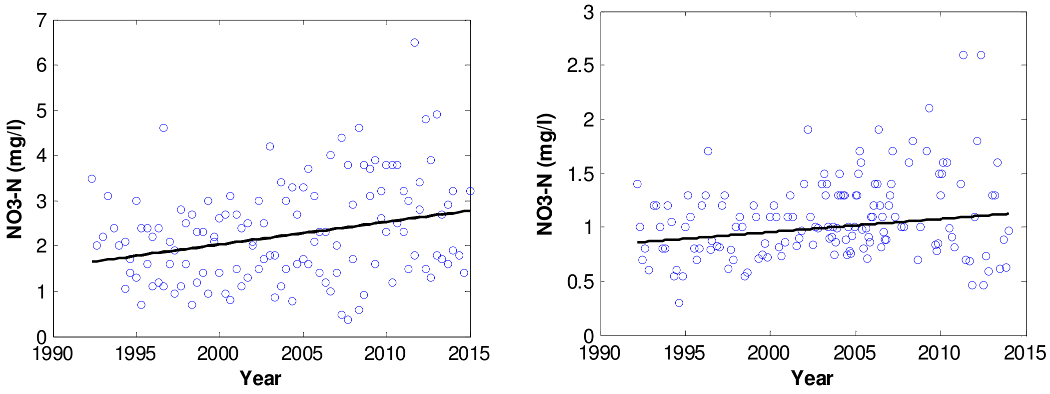
Fig. 2. Time series of total nitrogen concentrations in selected rivers in Estonia

For NO_3-N, statistically significant downward trend was detected only at three sampling sites: Tagajõgi-Tudulinna, Kunda-Lavi and Velise-Valgu (Fig.3). Notably, the monitoring station, Kunda-Lavi is rather representing the groundwater quality of Pandivere area, which belongs to Estonian NVZ. The downward trend in Kunda-Lavi station is difficult to explain since according to groundwater monitoring data, the content of nitrates in ground water bodies in the NVZ has not shown any decreasing tendency over the last decade, although the NO_3-N content in Lavi springs is already low, i.e. around 0.56 mg N/l. The factors that led to decreasing trend of NO_3-N in the rivers Tagajõgi and Velise-Valgu are probably the same that caused downward trend and downward tendency for TN, e.g. a large share (85% and 74%, respectively) of forest areas in the catchment and enhanced denitrification and biological uptake due to the insufficiently maintained drainage ditches. The share of agricultural land in the catchments is low (10% and 21%, respectively) owing to which the water quality mostly represents undisturbed catchments. NO_3-N forms only 28% of the TN in the river Tagajõgi and 41% in the river Velise.



Tagajõgi-Tudulinna

Kunda-Lävi



Pedja-Jõgeva

Ahja-Kiidjärve

Fig. 3. Time series of nitrate nitrogen concentrations in selected rivers in Estonia

The statistically significant (P-value < 0.05) upward trend in NO_3-N was found at nine stations: Pedja-Jõgeva, Pedja-Tõrve, Põltsamaa-Rutikvere, Porijõgi-Reola, Ahja-Kiidjärve, Ahja-Lääniste, Avijõgi-Mulgi, Pärnu-Tahkuse and Pärnu-Oore (Fig.3). Pronounced upward trend in NO_3-N in so many streams can indicate the enhanced mineralization of organic nitrogen. The upstream parts of the rivers Pedja, Põltsamaa and the source of river Avijõgi are located in the NVZ and fed by springs. The results obtained by monitoring the nitrate content in groundwater in the NVZ revealed increasing tendency in central and southern parts of the NVZ over the past years that probably contributed to the overall increase in NO_3-N content in these rivers. The increase over 5 mg NO_3/l occurred in 53 groundwater monitoring sites and the increase by 1 to 5 mg NO_3/l in 22% of sites between the periods 2004–2007 and 2008–2011, respectively (Keskkonnaministeerium, 2012). The increasing NO_3-N levels can be attributed to the increased use of nitrogen fertilisers, e.g. by 1.7 times higher in 2008–2011 compared to that in 2004–2007 in the Jõgevamaa county where the river catchments are located. This increase in the consumption of fertilisers was accompanied by the increase in cereal yields in this county by only about 19% during the same period, thus indicating the higher risk for loss of excess nitrogen.

Upward trend in NO_3-N in the rivers Pedja, Põltsamaa, Porijõgi, Ahja and Avijõgi can, to some extent, be explained by the statistically significant increasing trend of inorganic nitrogen content in precipitation measured at meteorological stations located within or near the river catchments (Sademete seire, 2015). Nitrogen concentrations are particularly high during winter season when most of the nitrogen loss from agricultural land typically occurs (Øygarden *et al.,* 2014). Annual deposition of nitrogen measured at the Alam-Pedja, Loodi and Otepää meteorological stations has been rather high reaching to 6.6 kg N/ha in 2014 (Sademete seire, 2015).

The statistically significant upward trend in NO_3-N in the rivers Porijõgi, Ahja and Avijõgi was accompanied by the decreasing tendency in TN concentrations, e.g. the share of inorganic nitrogen in TN was increasing. The subsurface drainage water monitoring results at selected fields in Tartu country, where almost the entire catchment of river Porijõgi is located, revealed a high nitrate content, which exceeded 50 mg NO_3/l in all samples tested during 2007–2013 (PMK, 2014). Agricultural land covered more than 50% in Porijõgi catchment and expanded over 27% since 2006. Thus, this upward trend can be attributed to more intensive agricultural production. The predominant substrate on the river bed of the river Ahja mostly consists of sand and gravel, and its water is rich in oxygen. These natural conditions favour the growth of nitrobacteria and helps in enhancing the nitrification process. However, intensification of agricultural activities, particularly the noted increase in application of manure by 56% between the periods 2007–2009 and 2010–2013 in Põlvamaa county where the Ahja catchment is located, is likely to be a more dominant factor influencing the NO_3-N content in the river.

The upward trend in NO_3-N was also detected in Pärnu-Tahkuse and Pärnu-Oore that are located in the downstream of river Pärnu - one of the longest rivers in Estonia. This upper reaches of the river Pärnu flow through the most intensively used agricultural land area in Estonia - Järvamaa country. The river catchment further includes large mire systems, floodplain grasslands and forests. Due to the large water volume and diverse river basin characteristics, the changes in NO_3-N concentrations in river Pärnu need more detailed investigations and perhaps cannot be directly attributed to the recent changes in nutrient emissions in the river catchment.

Conclusions

- Nitrogen concentration in most of the rivers and sampling sites did not reveal any statistically significant increasing or decreasing trends. It can probably be explained by the time lag between changes in the land use practices and water quality as well as a temporal change in the direction of the trend over the study periods.

Statistically significant (P-value < 0.05; two-sided test) downward trend in TN was detected at 13 monitoring stations, representing both agricultural as well as forest areas. The same downward trend for the same monitoring stations was detected in an earlier study conducted for the period 1992–2006 (no previous results were available for Väike-Emajõgi-Tõlliste).

- Statistically significant (P-value < 0.05; two-sided test) upward trend in TN was observed at four sampling sites. Since 1992, such upward trends were detected for the first time.
- The statistically significant (P-value < 0.05; two-sided test) downward trend in NO_3-N was detected at three sampling sites while the upward trend was found at nine monitoring stations. In addition, the upward trend in NO_3-N in the rivers Porijõgi, Ahja, and Avijõgi was accompanied by the decreasing tendency in TN concentrations, e.g. the share of inorganic nitrogen in TN had increased.
- The catchment characteristics and land use practices in the monitoring stations where the upward trend in NO_3-N was detected are different. Therefore, it is hard to come up with a single major factor to explain such a phenomenon. The most probable reason could be the intensification of agricultural activities in the rivers' catchments, such as the expansion of agricultural land and increased use of nitrogen fertilisers. However, more detailed investigation for each concrete catchment is needed to suggest more reliable explanations and draw cause-effect relationships between the changes in river catchments and observed water quality parameters. In addition, the relatively large size of the investigated rivers (in general more than 200 ha) where any trend in TN or NO_3-N was not observed can lead to remarkable time lag between the changes in land use practices and water quality.
- The increase of NO_3-N content in four monitoring sites of NVZ is particularly alarming. Only one river in NVZ indicated statistically significant decreasing trend in NO_3-N. Perhaps, inculcating good practices by the farmers located in NVZ and development of more specific action plan to control nutrient losses is needed.

References

Arheimer, B; Liden, R. 2000. Nitrogen and phosphorus concentrations from agricultural catchments – influence of spatial and temporal variables. *Journal of Hydrology*, 227(1-4), 140-159. http://dx.doi.org/10.1016/S0022-1694(99)00177-8.

Bechmann, M.; Stålnacke, P. 2005. Effect of policy-induced measures on suspended sediments and total phosphorus concentrations from three Norwegian agricultural catchments. *The Science of the Total Environment*, 344(1-3), 129-142. http://dx.doi.org/10.1016/j.scitotenv.2005.02.013.

EC, 1991. Council Directive concerning the protection of water against pollution caused by nitrates from agricultural sources (91/676/EC).

EC, 2000. Council Directive establishing a framework for Community action in the field of water policy (2000/60/EC).

FAO, 2006. *Country Pasture/Forage Resource Profiles* [online], [cited 25 May 2015]. Available at: http://www.fao.org/ag/agp/AGPC/doc/Counprof/PDF%20files/Estonia.pdf.

Gambrell, R. P.; Gilliam, J. W.; Weed S. B. 1975. Nitrogen losses from soils of the North Carolina Coastal Plain. *Journal of Environmental Quality*, 4(3), 317–322. http://dx.doi.org/10.2134/jeq1975.00472425000400030006x.

HELCOM, 2007. *HELCOM Baltic Sea Action Plan.* HELCOM Ministerial Meeting Krakow, Poland, 15 November 2007.

Hipel, K.W.; McLeod, A.I.; Weiler, R.R. 1988. Data analysis of water quality time series in Lake Erie. *Water Resources Bulletin*, 24 (3), 533–544.

Hirsch, R.M.; Slack, J.R.; Smith, R.A. 1982. Techniques of trend analysis for monthly water quality data. *Water Resources Research*, 18(1), 107-121. http://dx.doi.org/10.1029/WR018i001p00107.

Iital, A.; Stålnacke, P.; Deelstra, J.; Loigu, E.; Pihlak, M. 2005. Effects of large-scale changes in emissions on nutrient concentrations in Estonian rivers in the Lake Peipsi drainage basin. *Journal of Hydrology*, 304(1-4), 261–273. http://dx.doi.org/10.1016/j.jhydrol.2004.07.034.

Iital, A.; Pachel, K.; Loigu, E.; Pihlak, M.; Leisk, Ü. 2010. Recent trends in nutrient concentrations in Estonian rivers as a response to large-scale changes in land-use intensity and life-styles. *Journal of Environmental Monitoring*, 12, 178-188. http://dx.doi.org/10.1039/B912923E.

Kendall, M.G. 1975. *Rank Correlation Methods.* 4th ed., Charles Griffin, London.

Keskkonnaagentuur, 2015. *Eesti Keskkonnaseire 2013* (Estonian Environmental Review 2013) (in Estonian), Tallinn, Estonia.

Keskkonnaagentuur, 2014a. *Estonian Environmental review 2013* [online], [cited 25 May 2015]. Available at: http://www.keskkonnaagentuur.ee/et/review2013.

Keskkonnaagentuur, 2014b. Yearbook forest 2013. Tartu, Estonia.

Keskkonnaministeerium, 2012. *Nõukogu direktiivi 91/676/EMÜ, veekogude kaitsmise kohta põllumajandusest lähtuva nitraadireostuse eest, täitmine Eestis 2008-2011* (Report on the implementation of Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources for the period 2008–2011) (in Estonian), Tallinn, Estonia.

Mann, H.B. 1945. Nonparametric tests against trend. *Econometrica*, 13(3), 245–259.

Onoz, B.; Bayazit, M. 2003. The power of statistical tests for trend detection. *Turkish Journal of Engineering and Environmental Sciences*, 27, 247–251.

Pachel, K.; Klõga, M.; Iital, A. 2012. Scenarios for reduction of nutrient load from point sources in Estonia. *Hydrology Research*, 43(4), 374-382. http://dx.doi.org/10.2166/nh.2012.136.

PMK 2014. *Eesti maaelu arengukava 2007-2013* (Estonian rural development plan) (in Estonian), Saku, Estonia, 2014.

Povilaitis, A. 2006. Impact of agriculture decline on nitrogen and phosphorus loads in Lithuanian rivers. *Ecologija*, 1, 32-39.

Sademete seire, 2015. (Precipitation monitoring, 2015) (in Estonian). Estonian Environmental Research Centre, Tallinn, Estonia.

Skaggs, R. W.; Breve, M. A.; Gilliam, J. W. 1994. Hydrologic and water quality impacts of agricultural drainage. *Critical Reviews in Environmental Science and Technology*, 24 (1), 1-32.

Sileika, A.S.; Stålnacke, P.; Kutra, S.; Gaigalis, K.; Berankiene, L. 2006. Temporal and spatial variation of nutrient levels in the Nemunas River (Lithuania and Belarus). *Environmental monitoring and assessment*, 122 (1-3), 335-354.

Statistics Estonia 2002. *Agricultural census 2001.* Statistical Office of Estonia, Estonia.

Statistics Estonia 2004. *Indicators of sustainable development*. Statistical Office of Estonia, Estonia.

Statistics Estonia 2006. *Agriculture Yearbook.* Statistical Office of Estonia, Estonia.

Statistics Estonia 2014a. *Statistical Yearbook of Estonia*. Statistical Office of Estonia, Estonia.

Statistics Estonia 2014b. *Agriculture in Figures 2013*. Statistical Office of Estonia, Estonia.

Stålnacke, P.; Aakerøy P.A.; Blicher-Mathiesen, G.; Iital, A.; Janson, V.; Koskiaho, J.; Kyllmar, K.; Lagzdins, A.; Pengerud, A.; Povilaitis, A. 2014. Temporal trends in nitrogen concentrations and losses from agricultural catchments in the Nordic and Baltic countries. *Agriculture, Ecosystems and Environment*, 198, 94-103. http://dx.doi.org/10.1016/j.agee.2014.03.028.

Stålnacke, P.; Grimvall, A. 2001. Semiparametric approaches to flow-normalisation and source apportionment in substance transports in rivers. *Environmetrics*, 12(3), 233-250. http://dx.doi.org/10.1002/env.459.

Stålnacke, P.; Grimvall, A.; Libiseller, C.; Laznik, M.; Kokorite, I. 2003. Trends in nutrient concentrations in Latvian rivers and the response to the dramatic change in agriculture. *Journal of Hydrology*, 283 (1-4), 184-205. http://dx.doi.org/10.1016/S0022-1694(03)00266-X.

Tarand, A.; Jaagus, J; Kallis A. 2013. *Eesti kliima minevikus ja tänapäeval*. (Estonian climate in the past and today) (in Estonian), Tartu: Academic Press.

Øygarden, l.; Deelstra, J.;Lagzdins, A.; Bechmann, M., Greipsland, I.; Kyllmar, K.; Povilaitis, A., Iital, A. 2014. Climate change and the potential effects on runoff and nitrogen losses in the Nordic–Baltic region. *Agriculture, Ecosystems and Environment*, 198, 114–126. http://dx.doi.org/10.1016/j.agee.2014.06.025.