

## Nutrient retention efficiency of small regulated streams during the season of low-flow regime in Central Lithuanian lowland

Valerijus Gasiūnas and Jelena Lysoviėnė

### ABSTRACT

Small streams are polluted with nutrients when crude or partially treated wastewater flows from settlements. The aim of the study was to determine the efficiency of small streams to self-purify themselves of nutrients during the season of low-flow regime. The study was carried out in five regulated streams with catchments of up to 30 km<sup>2</sup> in the Central Lithuanian lowland. The retention of nitrogen (N) and phosphorus (P) compounds was studied up to 5.2 km downstream from the settlements. Owing to the pollution load from settlements, the concentrations of total N increased from 2.0–3.0 above the settlements to  $6.75 \pm 2.07$  mg L<sup>-1</sup> below; the concentrations of total P increased from 0.03–0.07 to  $0.56 \pm 0.30$  mg L<sup>-1</sup>, with the stream's ecological state deteriorating to 'poor' and 'bad'. For the calculation of total N retention, with respect to the pollution load and the distance from the settlement, an empirical equation was derived. Calculations show that with a pollution load of 2.0 g N m<sup>-3</sup> at 5.0 km distance, around 90% of total N can be retained. However, when the load is threefold greater, at the same distance only 65% of total N is retained. As a result of self-purification processes only about 50% of total P may be retained.

**Key words** | nutrients, pollution, self-purification, streams

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### INTRODUCTION

Anthropogenic activity influences the amount of pollutants in water bodies significantly. It affects the amount of pollutants either by point source pollution (e.g., wastewater streamed through outlet pipes) or non-point source pollution (Casey *et al.* 1993; Jordan & Weller 1996; Povilaitis 2008; Povilaitis *et al.* 2012).

Quantitative analysis of nutrients is important for assessing the state of aquatic ecosystems and the processes of eutrophication (Dodds & Welch 2000; Dodds *et al.* 2002). Small streams link terrestrial ecosystems to larger water bodies into which they flow. Therefore, small streams can regulate the transport of nutrients (e.g., Peterson *et al.* 2001).

Small streams are first to be negatively affected by human activity; the negative effects are most evident in the dry season. Straightening of streams and the inflow of drainage water and crude or only partially treated wastewater

from settlements into small streams also increase the amount of nutrients, which is delivered to larger rivers (Gai-liušis *et al.* 2001; Demars *et al.* 2005; Šmitienė & Gaigalis 2010).

The self-purification of streams reduces the concentration of nutrients within a relatively short distance, and may partially solve the problem of water quality (Elosegui *et al.* 1995), if the pollution-loading capacity of the water body is not exceeded. Ecologically, rivers have many advantages over standing water. Flowing water is less polluted by nutrients, has a better oxygen supply and faster purification processes (Vaikasas 2007). The concentration of pollutants can be decreased by diluting water with surface and ground water, or by integrated hydrological, biological and chemical processes, such as sedimentation, coagulation, evaporation, the deposition of colloid in the bottom of water body or the

biological decomposition of contaminants (Kummert 1989; Stream Solute Workshop 1990; Ifabiyi 2008).

Nitrogen and phosphorus retention is the integer of physical, chemical and biological processes in the hydrographic network; a part of the substances is transformed into gaseous form, assimilated biologically by aquatic plants and bacteria, or accumulates in the sediment of the water body (Povilaitis 2008). Nitrogen is retained in aquatic ecosystems mainly by denitrification processes, nitrogen consumption by algae and macrophytes and the sedimentation of organic nitrogen. Phosphorus is retained largely in water by adsorption processes, the accumulation of its various forms in the bed sediments and phosphorus consumption by plants (Povilaitis *et al.* 2011).

The majority of self-purification studies in Lithuania were carried out in relatively clean streams or big rivers (Vaikasas & Dumbrasukas 2010). However, very little is known about the decrease of contaminant concentration in polluted streams (Haggard *et al.* 2001). Based on the theory of additional load (Odum *et al.* 1979), Martí *et al.* (2004) hypothesised that the permanent heavy load of pollutants – e.g., flowing from water treatment plants – alter ecological communities in these streams, and decrease the efficiency of self-purification in contrast to less contaminated streams.

The aim of the study was to determine nutrient retention efficiency of small regulated streams, owing to self-purification processes during the season of low-flow regime. The objective of this study was to determine the dependencies of nutrient retention on the pollution load and distance downstream from the settlements.

## MATERIALS AND METHODS

### Study area

Investigations were carried out in five regulated streams in Kėdainiai and Panevėžys districts, the lowland areas of the Nevėžis River in Central Lithuania. Central Lithuanian lowland areas are characterised by low absolute altitudes of up to 80–90 m. The area has an average annual rainfall of about 600–650 mm, with around 400 mm in the warm period. Rain and snow form the majority of the water supply to

the rivers of Central Lithuania (41 and 43%, respectively); ground water only constitutes 16% of the overall water supply because in this area soil is water impermeable and riverbeds are shallow. Small rivers freeze during the winter and can run dry in the dry season (Gailiušis *et al.* 2001).

The Nevėžis lowland is relatively wooded, and there are many agricultural landscapes, the majority of which are dominated largely by pasture and arable fields. Predominant soil types are *cambisols* and *luvisols* (Volungevičius & Kavaliauskas 2012). All streams under investigation are in the same geographical area of Lithuania, and are characterised by similar soils, and geological and hydrological conditions. The location of the investigated streams is shown in Figure 1.

The main criteria, according to which investigation sites were chosen, are as follows:

- catchment area of the stream;
- size of the settlement above the investigated stream;
- hydromorphological conditions of streams.

### Catchment area of the stream

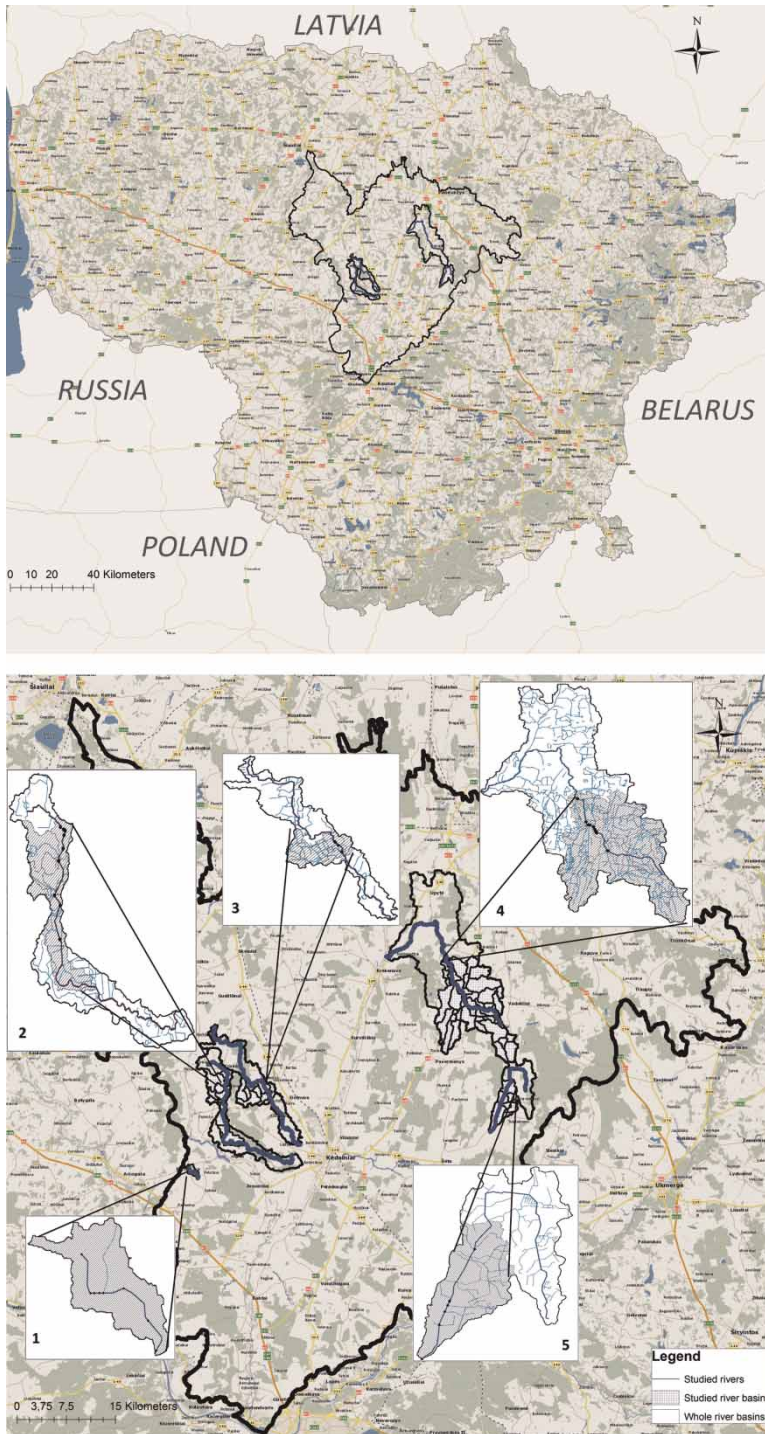
Investigation was carried out in small streams with a less than 30 km<sup>2</sup> catchment area in the investigation site. During the dry season, flow of the streams did not exceed 0.2 m<sup>3</sup> s<sup>-1</sup>. Catchment area of the studied streams was: Upelis, 2.24 km<sup>2</sup>; Smilgaitis, 28.97; Jaugila, 16.32; Upytė, 113.9; and Rudekšna, 18.2 km<sup>2</sup>. Upytė was investigated in the upper part of the stream and the catchment area in the investigation site equalled about 30 km<sup>2</sup>.

### Size of the settlement above the investigated stream

The investigations were carried out in small streams covering settlements with a population of 200–2,000 inhabitants.

### Morphological conditions of streams

Investigations were carried out in regulated streams. During the drainage of fields, the streams under investigation were straightened and turned into melioration ditches. Streams have a regular bed profile with a width of 0.3–1.5 m and a depth of 0.08–0.7 m. The beds are overgrown with



**Figure 1** | Location of the studied streams: 1, Upelis; 2, Smilgaitis; 3, Jaugila; 4, Upytē; 5, Rudekšņa. Sampling sites are represented by dots in the riverbed.

vegetation and contain alluvial deposits because the work of stream straightening was carried out 40–50 years ago, and streams have not been appropriately maintained in recent years.

## Experimental design

In order to evaluate the impact of settlements on water quality, water properties were investigated above and below settlements. The settlement with all the sewage outlets is regarded as a pollution source.

The research of streams was carried out in 2010–2012, during a season of low stream regime flow from June to October, when the stream water flow is the poorest, and the outside pollution has the greatest impact on stream water quality. In Central Lithuania, such a period of summer–autumn (the sampling period) lasts for 80–207 days, when the flow of streams is lowest (Bagdžiūnaitė-Litvinaitienė & Lukianas 2010). To evaluate the self-purification of streams, water was sampled during this period, when drainage is not working, in order to minimise the influence of dilution and pollutants coming from agricultural areas with the drainage water. The research was not conducted in Rudekšna (Pagiriai) in 2012, because the stream was flooded by beavers, and did not meet the initial study conditions.

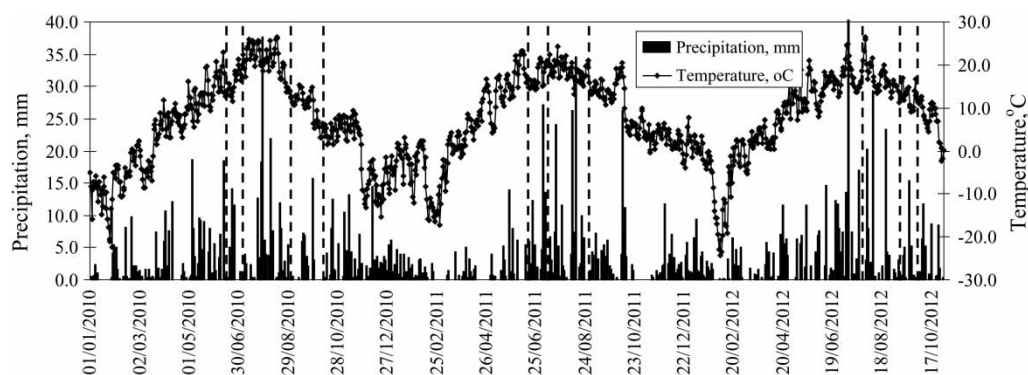
The distribution of air temperature and rainfall during the sampling period is presented in Figure 2. During June–October 2010, the areas under investigation received 470 mm of rainfall; in 2011, 425 mm; and in 2012,

423 mm of rainfall. The early summer of 2012 was humid, therefore the first water sample was only taken at the end of July. The rainfall data show that year 2010 was more humid than later years, but the distribution of rainfall during the year was not even. Sampling was scheduled for the time when dry weather settles and stream water drops to the lowest level. Water was drawn into bottles and transported immediately to the laboratory for testing. In the sampling, site measurements of the stream cross-section were taken and water speed was determined using a hydrometric mill. Laboratory analyses were conducted in a certified laboratory using standard European test methods.

The water sampling sites were situated as follows: in Upelis stream, above the Pernarava settlement, and 0.05, 0.2, 0.45, 1.07, 2.45, 4.25 km downstream; in Jaugila (Akademija), above the wastewater treatment plant outlet, and 0.08, 0.52, 1.55, 2.15 km downstream; in Smilgaitis (Krakės), above the wastewater treatment plant, and 0.07, 0.16, 0.49, 1.48; 2.44, 5.13 km; in Upytė (Ramygala), above the settlement, and 0.07 and 0.35, 0.72; 1.14, 1.25, 1.72, 5.17 km; in Rudekšna (Pagiriai), above the settlement, and 0.05, 0.61, 1.42, 3.7 km below the wastewater treatment outflow. The studied distance was confined to the mouth of the stream or a point of tributary inflow.

## Analytical methods

Stream water quality was estimated in accordance with the legal requirements of Lithuania. All the investigated streams



**Figure 2** | The distribution of precipitation and air temperature in the period of water sampling (meteorological station Dotnuva, Kedainiai district). Dotted lines represent the water sampling date.

had been subject to significant human influence and had been straightened, therefore their ecological potential was estimated following Chapter IV of *Methodology for the Surface Waterbodies' Condition Evaluation* (Valstybės žinios *Official Gazette*, 2010 No 29-1363). The ecological condition defines the quality of the structure and functioning of surface water-related ecosystems, evaluated by biological, hydromorphological, physical and chemical quality elements of the water body. However, in artificial and heavily modified water bodies, ecological potential rather than ecological condition is measured. Good ecological potential is defined by the status of biological, hydromorphological, physical and chemical quality parameters of a heavily modified or artificial water body, which meet the official requirements for water safety. **Table 1** presents the classification of ecological potential values, based on this methodology.

The impact of settlements on the streams' pollution was calculated under the assumption that sampling in a low-flow regime of the streams reflects the pollution of settlements, and minimises outside pollution from agricultural land.

### Statistical processing

Multiple regression analysis of experimental data was carried out under the hypothesis that there is a dependency between nutrients (P or N) retention on the load from the pollution source and the distance downstream to the pollution source. Mathematical and statistical evaluation of data was carried out using the program STATISTICA 7.0.

## RESULTS AND DISCUSSION

### Impact of the settlements on the quality of stream water

Streams flowing through the settlements are polluted with nutrients because the wastewater entering the streams is treated insufficiently. In small settlements, with a population equivalent (PE) of up to 2,000 people, the requirements for the removal of phosphorus and nitrogen compounds from wastewater in the treatment facilities are not regulated. Streams are also polluted by the release of untreated wastewater. In a dry period, when the stream flow is minimal, the influx of pollutants from the settlements influences water quality significantly. The average load from the settlement to the stream was calculated according to the measured discharges of streams and analysed concentrations of nutrients. Average stream flow during the season of low-flow regime and the stream load with nutrients are presented in **Table 2**.

As evidenced in **Table 2**, not all the inhabitants of settlements are connected to the centralised sewage network, therefore their sewage is not treated. The per capita load of pollutants was calculated using the data presented in **Table 2**. Calculation data are presented in **Figure 3**. As can be seen in the graph, the per capita load of pollutants increases with an increasing number of inhabitants in the settlement.

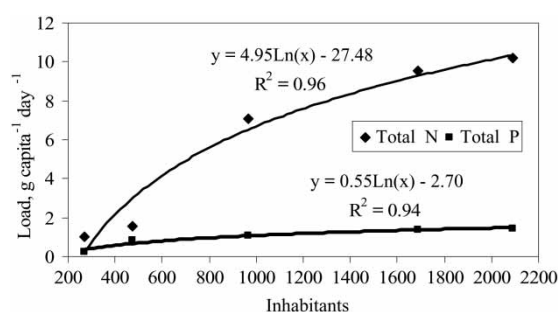
Stream flow and the extent of pollution load affected the stream water quality below the settlements. Changes in the concentrations of nutrients below the settlement are presented in **Table 3**.

**Table 1** | Potential ecological classes of the streams, attributed to strongly altered waterbodies, and channels by physical-chemical quality indices in Lithuania (Valstybės žinios *Official Gazette*, 2010 No. 29-1363)

Criteria of ecological potential classes by the values of physical-chemical quality indices					
Indices	Maximum good	Good	Average	Poor	Bad
Total N, mg L <sup>-1</sup>	<2.00	2.00–3.00	3.01–6.00	6.01–12.00	>12.00
N-NH <sub>4</sub> , mg L <sup>-1</sup>	<0.10	0.10–0.20	0.21–0.60	0.61–1.50	>1.50
N-NO <sub>3</sub> , mg L <sup>-1</sup>	<1.30	1.30–2.30	2.31–4.50	4.51–10.00	>10.00
Total P, mg L <sup>-1</sup>	<0.100	0.100–0.140	0.141–0.230	0.231–0.470	>0.470
P-PO <sub>4</sub> , mg L <sup>-1</sup>	<0.050	0.050–0.090	0.091–0.180	0.181–0.400	>0.400

**Table 2** | The average flow of streams below the settlement or below the wastewater flow, and the load of pollutants, according to total N and total P from 2010 to 2012, in a low-flow regime of the streams

Name of the settlement	Number of inhabitants/ access to the sewage network	Name of the stream	Average flow of stream below the settlement, m <sup>3</sup> s <sup>-1</sup>	Average stream load according to total N, g d <sup>-1</sup>	Average stream load according to total P, g d <sup>-1</sup>
1 Pernarava	270/0	Upelis	0.0019 ± 0.0014	277.5 ± 202.6	62.5 ± 50.6
2 Krakės	966/263	Smilgaitis	0.030 ± 0.024	6823.1 ± 3449.6	1057.2 ± 562.0
3 Akademija	2090/1630	Jaugila	0.052 ± 0.030	21294.2 ± 12731.9	3016.6 ± 3054.4
4 Ramygala	1688/752	Upytė	0.10 ± 0.09	16,066.1 ± 14,318.7	2300.6 ± 2276.3
5 Pagiriai	473/238	Rudekšna	0.017 ± 0.0018	737.5 ± 360.3	407.1 ± 331.0

**Figure 3** | Per capita stream load according to total N and P, depending on the number of inhabitants in the settlement.

Based on an analysis of the data in Table 3 it can be seen that there is little difference in the concentrations of nutrients above the settlements in all studied streams. It can be stated that in the intensively farmed land of Central Lithuania, the average concentrations of nutrients in the streams, during the season of low-flow regime, are as follows: the concentration of total N is 2.0 to 3.0 mg L<sup>-1</sup> and total P is

0.03 to 0.07 mg L<sup>-1</sup> range; i.e., the ecological state of the streams according to total N is good; and according to total P is maximally good (see Table 1). In Lower Silesia (Poland), Hus & Pulikowski (2011) found that water flowing out of small agricultural catchments contains considerable amounts of total N, from 3.21 to 16.85 mg L<sup>-1</sup>.

Stream water quality below the settlements was reduced significantly. The concentration of total N increased by 2 to 2.5 times, and the concentration of total P increased dramatically, from 4.5 to 14.0 times. Stream ecological potential according to nitrogen concentration, whose rating scale is shown in Table 1, declined from the 'maximum good-good' to 'average'. Meanwhile, stream ecological potential in terms of phosphorus fell from 'maximum good' to 'poor' and 'bad'. As a result of domestic pollution, N-NH<sub>4</sub> concentration in the stream water of Upelis below Pernarava increased by more than 25 times; in Smilgaitis below Krakės by 50 times; and in Jaugila below Akademija by as much as 84 times.

**Table 3** | Changes in concentrations of analysed water parameters in the streams under investigation, mean ± standard deviation

Settlement/Stream	Measurement point	Total N, mg L <sup>-1</sup>	N-NH <sub>4</sub> , mg L <sup>-1</sup>	N-NO <sub>3</sub> , mg L <sup>-1</sup>	Total P, mg L <sup>-1</sup>	P-PO <sub>4</sub> , mg L <sup>-1</sup>
Pernarava/Upelis	1	1.99 ± 0.77	0.09 ± 0.03	1.51 ± 0.70	0.03 ± 0.01	0.03 ± 0.01
	2	4.16 ± 1.59	2.29 ± 1.33	0.58 ± 0.60	0.54 ± 0.34	0.37 ± 0.26
Krakės/Smilgaitis	1	2.24 ± 1.03	0.09 ± 0.05	0.15 ± 0.07	0.12 ± 0.06	0.05 ± 0.03
	2	5.63 ± 2.82	3.22 ± 2.81	1.08 ± 0.99	0.71 ± 0.59	0.33 ± 0.18
Akademija/Jaugila	1	3.09 ± 2.39	0.07 ± 0.04	1.60 ± 1.43	0.05 ± 0.02	0.02 ± 0.01
	2	8.17 ± 4.93	7.01 ± 3.86	2.16 ± 1.02	0.62 ± 0.42	0.58 ± 0.40
Ramygala/Upytė	1	3.08 ± 1.39	0.11 ± 0.06	1.90 ± 1.81	0.07 ± 0.04	0.03 ± 0.01
	2	6.22 ± 2.65	1.25 ± 0.87	3.75 ± 1.37	0.41 ± 0.22	0.31 ± 0.18
Pagiriai/Rudekšna	1	1.78 ± 0.98	0.094 ± 0.1	0.58 ± 0.81	0.078 ± 0.036	0.053 ± 0.025
	2	1.35 ± 0.27	0.42 ± 0.23	0.04 ± 0.05	0.35 ± 0.20	0.29 ± 0.19

Measurement points: 1, above the settlement; 2, below the settlement.

## Retention efficiency of nutrients

Owing to continuous stream self-purification processes and dilution, the concentration of pollutants in the water decreases with increasing distance from the pollution source. One of the indicators of settlement household pollution is the increase in chloride concentration in the water. Since chlorides are difficult to remove from the water, they can be used to evaluate potential stream water dilution, when the distance from the pollution source is increasing. In order to evaluate the potential dilution effect, the change in chloride concentration in the water within the investigated distance length below settlements was analysed. The data of chloride concentration change are presented in Table 4.

With the exception of Rudekšna stream, chloride concentrations below all the settlements increased considerably. Elevated Cl concentrations varied little within the investigated distance range, indicating that the potential dilution is minor. Since the research was carried out in a low-flow regime period, when drainage is not functioning and dilution is minor, stream purification is dominated by processes that are influenced little by dilution. The flow in Rudekšna stream was quite large compared to pollution load. Therefore the pollution load did not significantly affect the chloride concentration due to dilution.

The dynamics of changes in nutrient concentrations in the Smilgaitis stream below Krakės settlement is depicted graphically in Figure 4. In other streams, the character of dynamics was similar.

The concentrations above the settlements of the parameters presented in Figure 4 are listed in Table 3. Nitrate concentrations increased steadily with the increasing distance. At 1.5 km distance from the settlement, the

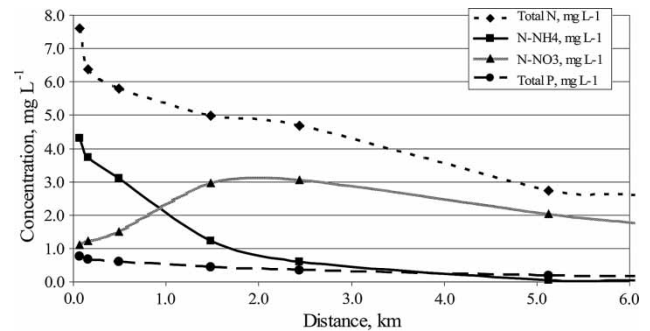


Figure 4 | The concentration change of nutrients in Smilgaitis stream water below Krakės.

concentrations began to decline, yet at the final point of investigation they were still about four times higher than those above the settlement.

Research on the other streams showed that, in Jaugila stream, the analysed distance of 2.15 km below the pollution source was insufficient to reach the initial concentrations of nutrients that were recorded above the settlement. Total N concentration decreased by 18.8% and total P concentration by only 11.7%.

Only the concentration of N-NH<sub>4</sub> reached the initial concentration recorded above the pollution source, at a distance of 1.5 km in Upytė below Ramygala settlement. Nitrate concentration at 5.17 km distance was 1.8, and total N was 1.37 times higher than that above the pollution source. Total P concentration at this distance was twice the initial concentration above Ramygala.

Total N concentrations in Rudekšna stream fluctuated within the range of the initial level above the settlement. Concentration of total P by the settlement was 5.7 times higher than the initial concentration above the settlement, and decreased to twice the concentration at the furthest analysed point below the settlement (3.7 km).

In Upelis stream, N-NH<sub>4</sub> concentration decreased steadily, and from the distance of 2.5–3.0 km below the settlement equalled the concentration above the settlement. Phosphorus compounds decreased, but did not reach the initial level at a distance of 4.25 km below the pollution source. Total P concentration decreased by only 50%.

The dynamics of change in nutrient concentrations in the analysed streams reveal a common pattern. The concentration of N-NH<sub>4</sub> rises steeply below the settlement,

Table 4 | Average chloride concentration in the studied streams in 2010–2012

Name of the stream	Investigated length of the stream distance below settlement, km	Cl concentration above the settlement	Average Cl concentration within the distance range
Upelis	4.25	16.95	28.23 ± 1.24
Smilgaitis	2.15	25.8	28.78 ± 2.46
Jaugila	5.13	26.71	43.01 ± 2.97
Upytė	5.17	21.7	33.33 ± 1.10
Rudekšna	3.7	23.22	22.45 ± 1.32

and indicates recent pollution.  $\text{N-NH}_4$  concentration decreases with increasing distance from the pollution source, but simultaneously,  $\text{N-NO}_3$  concentration increases. The form of nitrogen changes owing to nitrification processes.

Data presented in the graphs of Figure 4 show that the concentrations of nutrients decrease with the increasing distance from the pollution source. The analysis of concentrations does not fully reflect the stream self-purification processes, owing to the differences between stream loads and discharges. Stream pollution load with certain nutrients was calculated. Mean values of stream pollution load within the investigated time period are given in Table 5. The data show that the flow of the streams and their load of pollution differ significantly.

For each test point, the decrease of pollutants in  $1\text{ m}^3$  of water at a certain distance from the pollution source was calculated. From the statistical analysis of the data, Equation (1) was derived, which calculates the dependence of total N retention on the load from the pollution source and the distance downstream from the pollution source.

$$z = 0.36x + 0.52y - 1.0088 \quad (1)$$

$$R^2 = 0.63, \quad p = 0.0004 \quad 0 < x < 6.0; \quad 0.5 < y < 10.0$$

where ( $z$ ) is the total N retention,  $\text{g N m}^{-3}$ , ( $x$ ) is the distance from pollution source in km and ( $y$ ) is the load from pollution source, according to total N,  $\text{g N m}^{-3}$ .

In order to evaluate stream self-purification from total N, total N retention with respect to different pollution loads and increasing distance from the settlement was

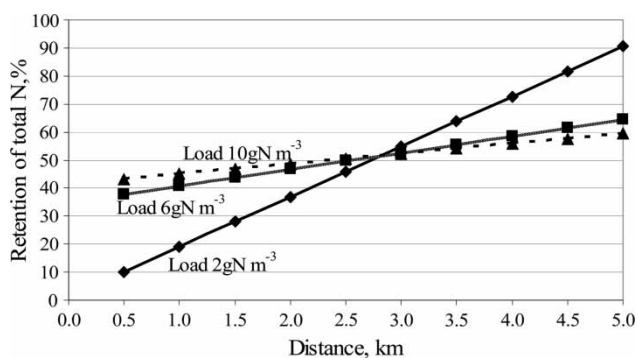
**Table 5** | The average flow of the streams below the settlement and the average pollution load, according to total N and P in the period 2010–2012

No.	Name of the stream	Average stream daily flow below the settlement, $\text{m}^3 \text{d}^{-1}$	Average stream load according to total N, $\text{g N m}^{-3} \text{d}^{-1}$	Average stream load according to total P, $\text{g P m}^{-3} \text{d}^{-1}$
1	Upelis	$163 \pm 122$	$2.42 \pm 1.57$	$0.54 \pm 0.34$
2	Smilgaitis	$2620 \pm 2038$	$5.37 \pm 7.22$	$0.64 \pm 0.66$
3	Jaugila	$4471 \pm 2622$	$5.93 \pm 3.91$	$0.57 \pm 0.42$
4	Upytė	$8931 \pm 8064$	$3.66 \pm 3.05$	$0.38 \pm 0.19$
5	Rudekšna	$1452 \pm 152$	$0.49 \pm 0.16$	$0.27 \pm 0.19$

calculated according to Equation (1). N retention efficiency was recalculated as a percentage. The results are presented graphically in Figure 5. Calculations show that with a load from pollution source of  $2.0 \text{ g N m}^{-3}$  at 5.0 km distance, around 90% of total N can be retained. However, when the load is three times higher, at the same distance only 65% of total N is retained. Dodds *et al.* (2002) found that the distance at which nutrients are fully retained was higher in the streams with a higher pollution load. The slope angle of given curves shows that at the higher pollution load total N retention processes at 3.0 km distance are more intense (load 6.0 and  $10.0 \text{ g N m}^{-3}$ ) than at lower pollution loads ( $2.0 \text{ g N m}^{-3}$ ). The tendency suggests that retention processes are more extensive at a lower pollution load owing to lower concentrations of total N.

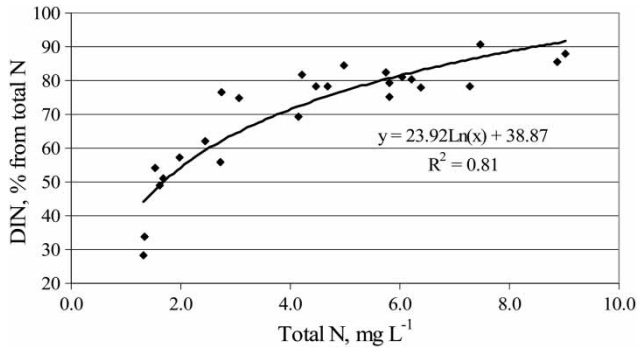
Dissolved inorganic nitrogen ( $\text{DIN} = \text{N-NO}_3 + \text{N-NH}_4 + \text{N-NO}_2$ ) is an important parameter for rivers with low hydraulic flow. The difference between total nitrogen and the load of DIN is the transfer of nitrogen into particles, retained via a sedimentation process. Recent studies show that a significant amount of immobilised nitrogen remains in organic form (either dissolved or particulate organic nitrogen) and is transported downstream in that form (Mullolland & DeAngelis 2000; Dodds *et al.* 2000; Wollheim *et al.* 2001).

Figure 6 presents the analysis of nitrogen composition below the pollution sources; most of the nitrogen is in its soluble form (DIN) at the highest concentration of total N. This fact indicates that nitrogen can be easily transported downstream. Owing to the transformation processes taking place in the flowing water, a part of the nitrogen is removed.



**Figure 5** | The dependency of total N retention in stream water on different loads, from pollution source and distance downstream.



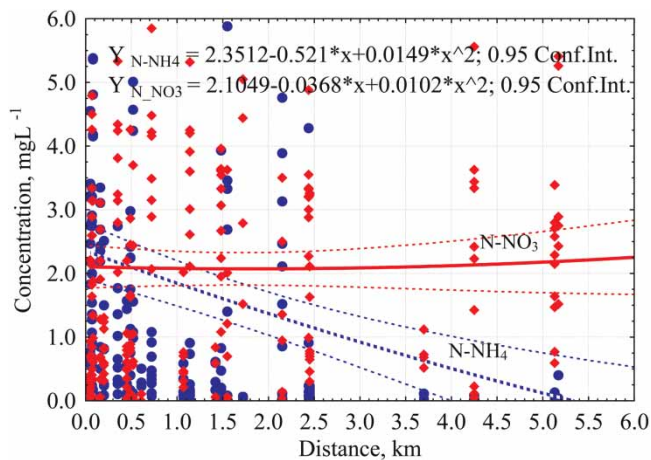


**Figure 6** | The dependence of dissolved inorganic nitrogen in the stream water below the pollution source on total N concentration.

Therefore, the concentration of total N decreases and nitrogen in organic form increases. In a low hydraulic flow, the latter can be retained in sediment or sequestered by biological processes.

The average  $\text{N-NH}_4$  concentration in stream water above the settlements was  $0.09 \pm 0.016 \text{ mg L}^{-1}$  and  $\text{N-NO}_3$  concentration  $1.38 \pm 0.78 \text{ mg L}^{-1}$ . Below the settlements  $\text{N-NH}_4$  concentration increased to  $3.52 \pm 2.21 \text{ mg L}^{-1}$ , and in Jaugila stream to  $6.24 \text{ mg L}^{-1}$ . The dynamics of  $\text{N-NH}_4$  and  $\text{N-NO}_3$  concentrations in stream water below the settlement is presented in Figure 7.

Although no statistically significant dependencies were found, the trends in concentration change suggest that the  $\text{N-NH}_4$  concentration decreases to the levels recorded above the settlements, at a distance of 4.0 km. Meanwhile, the nitrate concentration increases. This



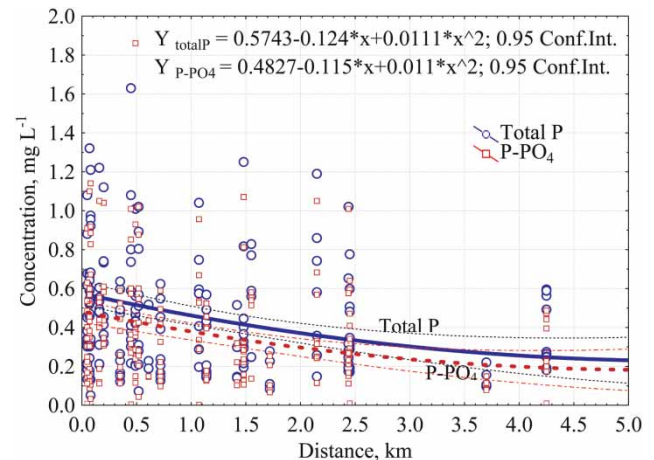
**Figure 7** | The dynamics of  $\text{N-NH}_4$  and  $\text{N-NO}_3$  concentrations in stream water below the settlements, with respect to distance downstream.

indicates that owing to the nitrification processes nitrogen from the ammonia is transformed into nitrate form. A part of the nitrogen is retained during the transformation process.

In the study by Martí *et al.* (2004), the decrease in  $\text{N-NH}_4$  concentration in 40% of the cases correlated with the increase in  $\text{N-NO}_3$  concentration. Their results confirmed the findings of other authors (House & Denison 1997; Robson & Neal 1997; Koning & Roos 1999), claiming that point pollution sources are a major threat to water quality. The influx of wastewater from the treatment facilities into the streams increases the concentrations of nutrients, and alters the dominant form of nitrogen in the water. Such a reversion to the  $\text{N-NH}_4$  form affects stream biodiversity negatively, especially fish communities (Miltner & Rankin 1998).

Similar to the concentrations of total N, total P concentrations downstream from the pollution source also decrease. With the data of all streams taken into account, the average total P concentration above the settlement was  $0.072 \pm 0.031 \text{ mg L}^{-1}$ . The changes in concentrations below the settlement are presented in Figure 8. The graph shows that the average concentration of total P at a distance of 5.0 km decreased from 0.55 to  $0.25 \text{ mg L}^{-1}$ .

Phosphate in its mineral form enters the streams with domestic pollution. The analysis of phosphorus concentrations showed  $\text{P-PO}_4$  concentration forms 39.7% of the total P upstream, whereas it forms 70–85% of total P below the settlement.



**Figure 8** | The changes in concentrations of total P and  $\text{P-PO}_4$  below the settlement.

Martí *et al.* (2004) estimated that the length of phosphate retention ranges from 0.14 to 14 km. Generally, the retention efficiency is lower in polluted streams when compared to non-polluted streams of similar size. Streams often require kilometre-scale distances to retain significant portions of P inputs from pollution sources (Haggard *et al.* 2001, 2004).

## CONCLUSIONS

The streams flowing through the settlements are polluted with nutrients owing to the flow of insufficiently treated wastewater. The load of pollutants depends on the size of the settlement. In the settlements with a population of about 2,000 inhabitants, the pollution load per capita, according to total N, was about five times larger than in the settlements with 400 inhabitants. The pollution load according to total P differed threefold.

In areas of intensive farming in Central Lithuania, the average concentration of nutrients, according to N in stream water above the settlement during the season of low-flow regime, is in the range of 2.0 to 3.0 mg L<sup>-1</sup>, with total P 0.03 to 0.07 mg L<sup>-1</sup>. The concentrations of total N in streams with the flow rate of up to 0.2 m<sup>3</sup> s<sup>-1</sup> below the settlements increased, on average, to 6.75 ± 0.07 mg L<sup>-1</sup>, and the concentrations of total P to 0.56 ± 0.30 mg L<sup>-1</sup>.

Below the pollution sources, the majority of nitrogen is in a soluble form (DIN) and an ammonia form is dominant. Average concentration of N-NH<sub>4</sub> above the settlements was 0.09 ± 0.016 mg L<sup>-1</sup>, and below the settlements it increased to 3.52 ± 2.21 mg L<sup>-1</sup>. For the calculation of total N retention, with respect to the pollution load and the distance from the settlement, an empirical equation was derived. Calculations show that with a pollution load of 2.0 g N m<sup>-3</sup> at a 5.0 km distance, around 90% of total N can be retained. However, when the load is three times higher, at the same distance only 65% of total N is retained.

Phosphorus in its mineral form enters the stream with domestic pollution. The concentrations of P-PO<sub>4</sub> above the settlement comprise 39.7 ± 20.0%, and below 70–85% of the total P. The investigated distance of 5.0 km was insufficient to see the complete retention of total P in stream

water. Owing to self-purification processes, only about 50% of total P may be retained.

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