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An Assessment of Self-purification of Regulated and Natural Streams

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Abstract. In these latter days it has become topical to reconsider, the technologies and practice of regulated for drainage purposes streams supervision, to find ways how to combine agricultural productivity and restore lost ecological balance at least partially. The article analyzes the influence of natural and regulated stream stretches on water quality and stream self-purification effectiveness. The analysis of nitrate concentration in water samples taken from natural and regulated stream stretches was conducted for the identification of water quality. Nitrate (NO_3) concentrations and their alternation during different seasons were studied. The conducted analysis revealed that stream nitrate self-purification is better in natural stream stretches. An average coefficient of self-purification recorded in the course of the research in natural stretches was 0.57, whereas in a regulated stretch – 0.09. On purpose to improve surface-water quality and self-purification effectiveness it is suggested to naturalize regulated stream stretches, to allow woody vegetation grow on slopes, to encourage meandering, pools and shoals forming processes in floodplains.

Keywords: water quality, self-purification, nitrate.

Conference topic: Water engineering.

Introduction

Anthropogenous (human-caused) activity has an impact on our whole environment including water ecosystems. The fundamental reasons for surface water contamination are insufficiently treated or untreated municipal effluents, animal farms pollution (point pollution), agricultural and atmosphere precipitation pollution (non-point pollution). Concentration of nitrogen compounds is mostly influenced by natural factors and intensity of agricultural activity (non-point pollution), whereas the amount of phosphorous compounds is mostly influenced by municipal household effluents (point pollution). Biogenic substances occurring in water bodies in various ways deteriorate water quality, affect biological diversity of ecosystems, and reduce recreational value of rivers.

It has been affirmed that water quality is also influenced by lakeside and riverside bogs referred to as wetlands (D'Arcy *et al.* 2007) because they retain (keep) part of biogenic substances getting into water bodies from nearby territories. Part of organic substances present in river channel (bed) deposits in wetlands during floods and mineralizes after flood subsides. Properly formed and well-kept vegetation belts significantly reduce scattered inflow of biogenic substances into water bodies from surrounding territories (Saunders, Kalff 2001).

Standing and flowing water bodies are distinct in their features (qualities), however all water bodies have the ability to reduce the concentration of biogenic substances occurring in them. The concentration of biogenic substances in a river decreases when river flow moves away from the source of pollution. Such physical processes as attenuation, adsorption, sedimentation, evaporation, chemical oxidation reduction reactions as well as biological processes are important for self-purification (Gasiūnas, Lysovienė 2014).

It has been argued (Ostroumov 2003; Tian *et al.* 2014) that processes of self-purification are influenced by vegetation, weed, microorganisms, invertebrates and fish. Nitrogen retention in water ecosystems is mostly determined by denitrification, nitrogen absorbed by weed and macrophytes and the accumulation of its organic forms in benthic sediments. Due to physical and chemical processes taking place in water wetlands are distinguished by great retention of biogenic and organic substances. The main processes determining nitrogen retention in water ecosystems are denitrification, nitrogen absorbed by weed and macrophytes and the accumulation of its organic forms in benthic sediments (Povilaitis *et al.* 2011).

The level of self-purification in each water body depends on such factors as water level, river flow rate, temperature etc. The retention of biogenic substances in rivers increases when river flow rate decreases. Macrophytes reduce the amount of biogenic substances in river water slowing flow rate, again, using these substances for its biological processes. Thus, part of biogenic substances arriving from the basin can be retained in shallow, slow, and overgrown with macrophytes upper reaches. In shallow and wide river channels (beds) denitrification is more intensive than in deep river channels (beds) because deep river channels (beds) have higher volume of water flowing though a wetland zone.

Zones favourable for denitrification are situated in porous oozy bottom sediments characterised by sufficient amount of organic substance and low water speed (Povilaitis *et al.* 2011). This factor is very important for the examination of possibilities of regulated and natural stream self-purification. It is commonly known that in the last century in the course of regulation of natural river and stream channels (beds) their natural meanders were destroyed and transverse profile of channels (beds) was created newly by artificial means. Regulated in such a way river became a straight ditch.

The conducted researches (Mi *et al.* 2015) show that mechanical naturalization of regulated streams improves their self-purification possibilities and increases stream biological variety. According to Maziliauskas *et al.* (2012), it is necessary to naturalize rivers and streams in order to improve their self-purification possibilities as well as morphological, hydraulic and ecological peculiarities.

Research objective is to determine the influence of natural and regulated for drainage purposes river stretches on stream self-purification effectiveness.

Research Object and Methods

The research includes the regulated and unregulated stretches of the following rivers: Terpinė, Žalesa, Kuosinė, Mėkla and Durbinis (Gailiušis *et al.* 2011). The stretches under consideration were coded. The first symbol shows the steam under consideration according to the first letter of stream name. The second symbol shows if the stream is regulated or natural. The place of sampling from natural stream channel (bed) is marked N, regulated – R. The last symbol is stretch number.

Terpinė is the right affluent of Nemunas. It is regulated from the springhead to 7.4 km and from 3.0 km to the stream outlet. Stream length is 9.0 km, basin area 12.2 km^2 (TN1; TN2; TR3; TR4; TR5).

Žalesa is the affluent of Neris. It is regulated from the springhead to 7.6 km. Stream length – 18.8 km, basin area – 97.1 km^2 (ZR1; ZR2; ZRN3; ZN4).

Kuosinė is the right affluent of Kena. It is regulated from the springhead to 16.0 and from 11.0 to 7.0 km. Stream length 20.1 km, basin area 45.3 km^2 (KR1; KRN2; KN3).

Mėkla is the left affluent (feeder) of Barupe, the lower reaches of the stream is ponded up. Stream length 26.9 km, basin area 93.3 km^2 (MR1; MR2; MRN3; MN4).

Durbinis is the affluent (feeder) of Lake Mastis. The stream is Stream length – 9.1 km; basin area –15.5 km^2 (DR1; DRN2; DN3).

The samples for water quality analysis were taken in accordance with sampling standard (LST EN ISO 5667-1:2007+AC:2007. Water quality - Sampling - Part 1: Guidance on the design of sampling programmes and sampling techniques (ISO 5667-1:2006)) taking into consideration all water sampling aspects.

The samples were taken once per month from 2013.08 to 2015.10. Nitrate (NO_3) concentrations were examined.

The amount of nitrates in water was measured by the photometer HANNA HI 83205, with a help of cadmium reducing method using HI 93728-01 reagents.

Nitrate (NO_3) concentrations in taken samples were examined in Hydraulics Educational Laboratory of Vilnius Gediminas Technical University.

According to average annual value of each index a water body is attached to one of five ecological state classes. Obtained average values of one year indexes were compared to the provided in Table 1 River ecological state classes according to physical-chemical quality elements indexes.

Table 1. River ecological state classes according to nitrate nitrogen amounts

Index	Criteria of river ecological state classes				
	Very good	Good	Average	Bad	Very bad
NO_3 mg l^{-1}	<5.75	5.75–10.18	10.19–19.92	19.93–44.27	>44.27

The following simplified river purification formula was used for the assessment of river self-purification of biogenic substances:

$$\alpha = ln\left(C_0 C_L^{-1}\right) L^{-1}, \quad (1)$$

where: C_0 – concentration of chemical substance at the beginning of river stretch under consideration mg l^{-1}; C_L – concentration of chemical substance at the end of river stretch under consideration mg l^{-1} ; L – river stretch length km; α – river purification coefficient km^{-1}.

Results

The conducted researches and analysis of their results show that nitrate concentrations in order of amount and period are distributed rather differently. The results of all researches obtained from Terpinė stream (see Fig. 1) exceed extreme values of good ecological state class (NO_3 = 10.18 mg l^{-1}).

The highest concentrations during vegetation period were recorded in sampling place TN1 (29.2; 38.5; mg l^{-1}). It is the second sampling point where we can see nitrate concentration reduction. This natural stretch of Terpinė stream includes plenty of meanders; therefore, river flow rate is slower and nitrate retention (adsorption) is larger. In cold months it is possible to notice the increase of nitrate amount in a natural stream stretch because of putrefactive plants and present frost soil.

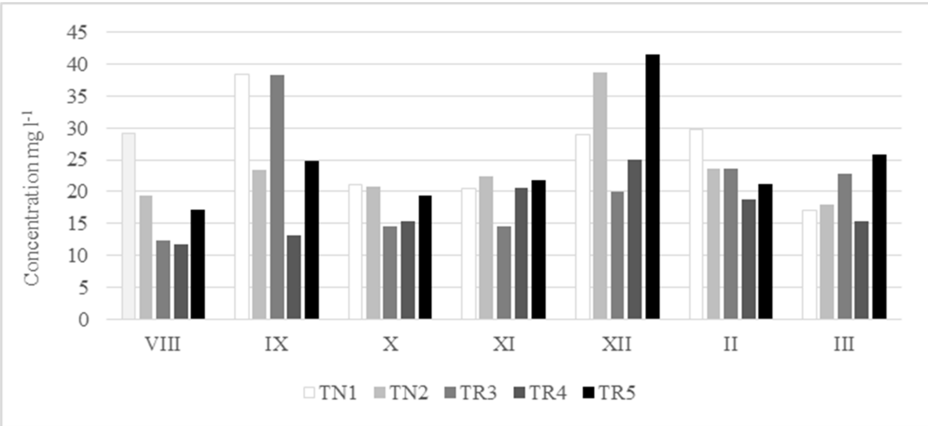

Fig. 1. Terpinė stream nitrate (NO3) concentrations during the period of researches in natural (N) and regulated (R) stream points

In comparison with natural stretches, regulated stream stretches show the increase of nitrate amount in downstream direction. The samples from TR3 and TR4 contain the smallest nitrate amounts in the course of the whole research. The weir equipped ahead the stretch TR3 – TR4 and a formed pond act as a sedimentator, so nitrates are retained (absorbed) throughout the year. The results obtained at this stretch can be strongly influenced by the stability of stream naturalization processes.

The slopes of stream channel (bed) are not high, so the possibility of soil slump is small. While there are no high slopes a wet zone at stream slopes is equal and greatly overgrown with grass vegetation, and due to smooth landscape, according to Jansson *et al.* (1994), slow river flow rate retains (keeps) nitrogen compounds, including nitrates. A natural part of Terpinė channel (bed) makes more impact on variation in water quality than a regulated part. Available data allows claiming that sample averages vary widely, given 95% reliability.

In the course of the research nitrate, amounts at point TR5 were higher than at point TR4, respectively 6.8–87.9%. This increase of concentrations can be determined by the intensive naturalization of stream channel (bed). The slopes of the stretch are very high and bluff; sharply downgoing landscape increases stream flow rate, which results in intensive bank erosion and slope soil slump, while vegetation dominates in the upper part of the slope and the protective shoreline belt (Burneika, Barvidiene 2014).

The research results obtained from Kuosinė stream (Fig. 2) show that water quality according to the criteria of river ecological state classes was bad in the course of five months, however only at point KR1. At the end of the regulated stretch, at point KRN2 water quality always corresponded to average or good ecological state class. At the third sampling, point KN3 water quality corresponded to a very good ecological state class in the course of 10 months (Stankaitis, Šaulys 2016). The worst water quality was noticed in the course of January–February at the abovementioned point KR1 (24.5; 23.8; mg l^{-1}).

Water quality in Mėkla stream from November to Match corresponded to a bad ecological state class, while at points MR1, MR2 and MRN3 from November to February it corresponded to very bad ecological state class. In the natural stream stretch, it is possible to observe an obvious nitrate quantity reduction in comparison with the regulated stream stretch; however, available data allows claiming that sample averages do not vary significantly, given 95% reliability.

Within vegetation period nitrate concentrations decrease, however bad ecological state classes often remain. Between points MR1, MR2 and MRN3 there is an affluent (feeder) which can exert a strong influence over nitrate concentration.

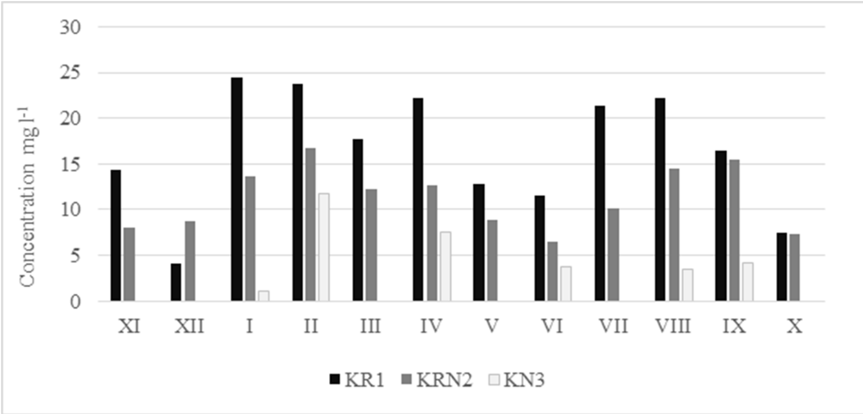

Fig. 2. Kuosinė stream nitrate (NO3) concentrations during researches, at natural (N) and regulated (R) stream points in the course of November–October

The highest concentration of nitrates in Durbinis stream was noticed within November–April (from 50.0 mgl^{-1} to 13.8 mgl^{-1}), and the lowest within June–October (from 0.0 mgl^{-1} to 2.2 mgl^{-1}). The increase of nitrate concentration is determined by non-point pollution from fields under cultivation as well as by domestic pollution. Within November–March at the beginning and at the end of the regulated stretch nitrate concentration did not change or increased 1.2–1.5 times, whereas at the end the regulated stretch – at the beginning of unregulated stretch nitrate concentration decreased 1.2–10.7 times.

In April, the stream was fully purified from the starting point of the regulated stretch to the end of the unregulated stretch. In other months, nitrate concentration was equal to 0.0 mgl^{-1}. Research results obtained from Durbinis stream show that at the regulated stretch the stream purifies insignificantly or nitrate concentration even increases, whereas at the unregulated stretch the stream purifies better. The assessment of river ecological state classes according to physical-chemical quality elements indexes (see Fig. 2) shows that according to nitrate concentrations very good river ecological state class was noticed in June–October, an average class was noticed in January and March, whereas nitrate concentration observed in November was 3 times over permitted limits which corresponds to very bad ecological state class.

In winter and in spring given the highest discharge of river (0.035 m^3/s), nitrate concentration is lower in comparison with nitrite concentration in summer and in autumn. It happens because the highest discharge of river is in spring, when a river gets water from snow melting, snowfall and rainfall. In this case, it can be seen that the discharge of river was higher in winter too, because the river was frozen only till February; and there were a lot of snow in December. In summer and autumn fields under cultivation are fertilized more. More nitrate pollutants get into rivers, and in summer river water is less diluted due to shallow waters (Marozaitė, Šaulys 2015).

In Žalesa stream nitrate concentration during vegetation period was close to 0 $mg\ l^{-1}$. After the end of vegetation it started to increase slightly, but at most points it did not exceed an extreme value of good river ecological state.

It is possible to place emphasis on the 3 point, at which nitrate concentration in July and August amount respectively 26.8 and 28.9 mgl^{-1}. Only at this, sampling point and only in July and August nitrate concentration exceeded maximum concentration of good river ecological state class – 10 mgl^{-1} (Jaksebogaitė, Barvidienė 2015). The researches of hydrological regime (behaviour) show that the greatest export of biogenic substances takes place during rainy season (Vanni *et al.* 2001).

Although nitrate concentration at ZRN3 point in July and August was high, nitrate concentration at ZN4 point was 0 mgl^{-1} during the whole reseach period.

According to Lysovienė and Gasiūnas (2011), the reduction of pollution concentration can be determined by the dilution of polluted water with surface and underground waters. It is necessary to take into consideration that the right feeder (affluent) flows into Zalesa at ZRN3-ZN4 stretch and inflowing stream water could dilute nitrate-polluted water of Žalesa and thus make a contribution to nitrate concentration reduction.

In accordance with obtained nitrate concentrations self-purification coefficients were calculated and there was assessed how the river could purify itself of pollutants.

Calculated self-purification coefficients show that streams purify better at unregulated stretches. An average nitrate self-purification coefficient of all streams under examination at unregulated stretches was equal to 0.53, and at regulated stretches – 0.05. The research of the streams revealed that the best self-purification coefficient was at natural stretch of Žalesa and was equal to 1.01 and at natural stretch of Kuosinė – (0.99) (see Fig. 3).

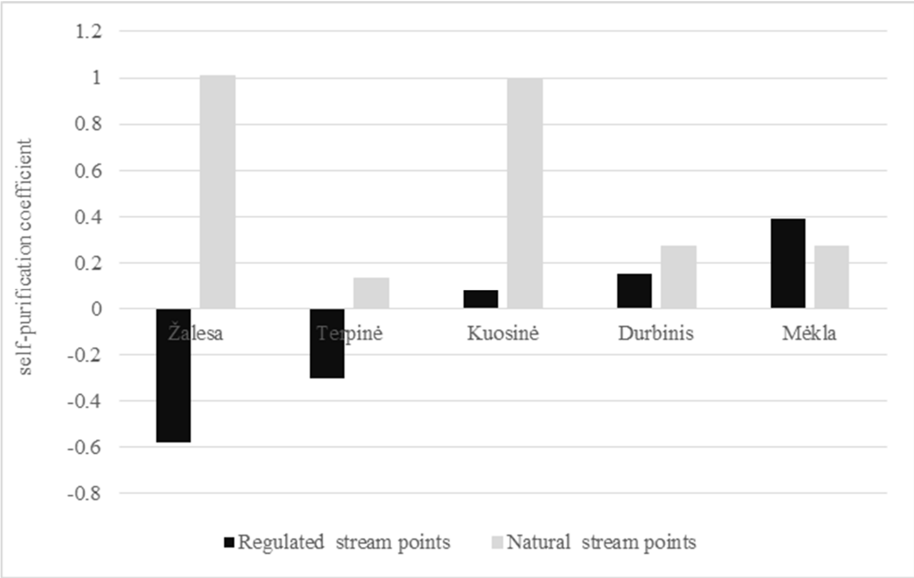

Fig. 3. Kuosinė, Mėkla, Durbinis and Žalesa nitrate (NO3) self-purification coefficient.

The worst self-purification koefficient was noticed at the regulated stretch of Žalesa –0.58. Obtained data allow stating that sample averages of natural and regulated stretches, given 95% reliability, vary widely in Žalesa, Terpinė and Kuosinė streams.

As stream self-purification is more intensive at natural stream stretches, in order to improve water quality of Lithuanian rivers and streams it is suggested to naturalize them whenever possible. Povilaitis *et al.* (2011) suggest the following channel (bed) naturalization ways at regulated stretches: remediation of meanders; reforming of channel cross-section; reforming of channel bottom heights and slopes; bank protection (bank strengthening); recovery of small mažų bays and quiet pools, increase of flora and fauna. The choice of ways depends on the specific peculiarities (conditions) of each river or stream.

As spring waterflood to flood plain at natural unregulated channels takes place periodically and is very useful for water self-purification, the naturalization of regulated streams and the return of regular flooding (overflowing) to valley can be very advantageous. All that shows that the issues of channel hydraulic conductivity, its monitoring and restoring as well as water quality issues should be solved in an integrated manner, taking into consideration not only economic (household), but also environment-oriented needs.

Conclusions

Water quality reseaches showed that water quality depends on point and non-point pollution, season, vegetation period and ecological state of river channel (bed). Water quality is greatly influenced by river's affluents (feeders), underground waters, wash-off. During warm season, in the course of vegetation nitrate concentration in water was smaller in most cases than during cold season. In certain cases increased nitrate concentration in summer can be determined by the fertilization of fields under cultivation.

The analysis of the effectiveness of self-purification of regulated and natural stretches showed that nitrite self-purification is better at natural stream stretches. An average self-purification coefficient at natural stretches amounted 0.53, whereas at regulated stretches – 0.05.

In order to improve water quality and self-purification effectiveness at regulated stream stretches it is suggested to naturalize regulated stretches to the extent possible without disregarding their drainage function: to allow woody vegetation grow on slopes, to form natural obstacles for water flow.

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