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Investigation of possible nutrient sources in Estonian rivers

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Abstract

A statistical model MESAW was used to estimate the diffuse emission coefficients of nitrogen in Estonia. This includes analysis of data on loads, point sources, land use types etc. Two studies were conducted to determine the emission coefficients for the whole Estonia and for a smaller study area near Tallinn. Investigations showed that in addition to arable lands, drained peat soils can be a significant source of nitrogen. In fact, our results show that the unit-area loads from drained peat soils may be 1.5 to 2.3 times higher than from arable lands. Additional detailed investigations and measurements are needed to support these conclusions. Comparison of emission coefficients for the whole Estonia and of the Tallinn catchment area indicated that the coefficients can vary significantly between sources and single years. Therefore it is suggested that the sources of nitrogen loads should be defined in a catchment area level rather than a country level.

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Keywords: Nutrients; rivers; water quality

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1. Introduction

One primary environmental management goal in the Baltic Sea region is the reduction of riverine nutrient loads. However, recent data analysis of Estonian rivers indicates that nitrogen concentrations have increased in some rivers,

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although the usage of fertilizers has decreased. An increase in nitrogen concentration has even been detected in watersheds with very low human activity [1]. Some authors [2, 3] have explained this with changes in processes in drained peat soils (e.g., changes in mineralization of organic matters and leaching of nutrients). In the current study, a statistical approach was used to estimate the emission coefficients of nitrogen from various diffuse source categories. Emission coefficients were estimated for the whole Estonian territory and for comparison purposes also for the drinking water catchment area of Tallinn city where the number of water quality sites are dense (Fig. 1).

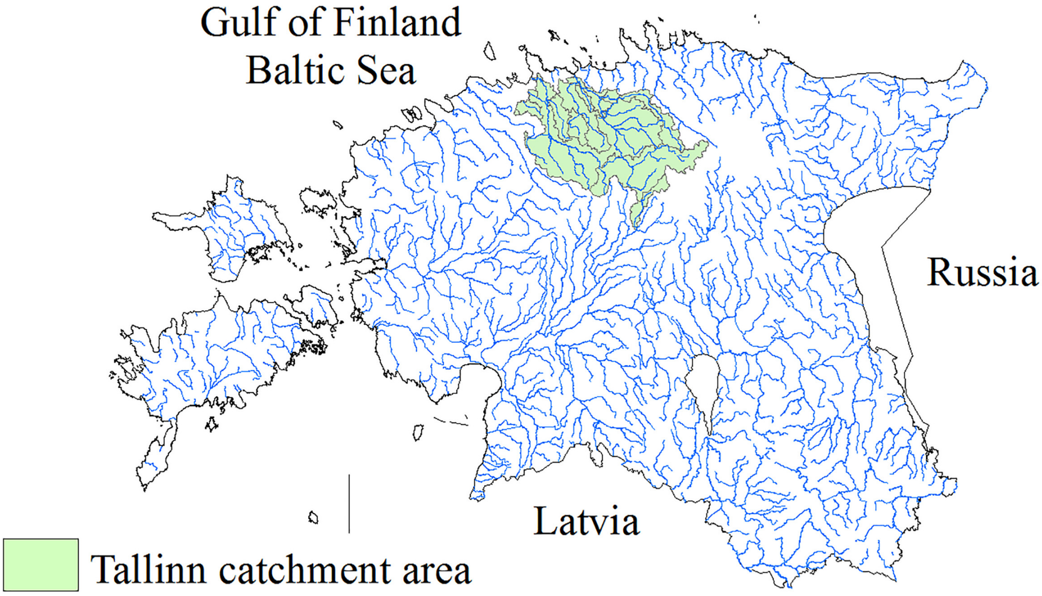

Fig. 1. Map of Estonia and location of Tallinn catchment area.

2. Methodology

For the source apportionment and retention estimates of nitrogen, the statistical model MESAW was used [4]. This model has earlier been shown to be suitable for source apportionment especially for areas with a dense network of water quality monitoring sites [4, 5]. This model-approach uses non-linear regression for simultaneous estimation of source strength (i.e. export coefficients to surface waters) for the different land use or soil categories and retention coefficients for pollutants in a river basin or lakes. The basic principles and major steps in the procedure can be described as follows: (1) estimation of riverine loads at each water quality monitoring site, (2) subdivision of the entire drainage basin into sub-basins. This is defined using the monitoring sites for water quality and the sub-basin upstream-downstream relationships (describing the river system). (3) derivation of statistics on land use, soil type, lake area, point source emissions and other relevant data for each sub-basin (4) using a general non-linear regression expression with loads at each sub-basin as the dependent/response variable and sub-basin characteristics as covariates/explanatory variables. In MESAW model the load at the outlet of an arbitrary sub-basin can be estimated from the following general expression (Eq. (1)).

$$L_i = \sum_{j=1}^{n}(1-R_{j,i})L_j + (1-R)S_i + (1-R)P_i + (1-R)D_i + \varepsilon_i \tag{1}$$

where

L_i = load at outlet of sub-basin *i*;
L_j = load at outlet of nearest upstream sub-basin *j*;
$R_{j,i}$ = retention on the way from outlet of sub-basin j till outlet of sub-basin i;
n = number of sub-basins located nearest upstream;
S_i = total losses from soil to water in sub-basin i;
P_i = point source discharges to waters in sub-basin i;
D_i = atmospheric deposition on surface waters in sub-basin i;
R = retention in sub-basin *i*.
ε_i = statistical error term.

The load at each sub-basin can be divided into contributions from sources located in sub-basins further upstream (the first term in Eq. (1)) and contributions from sources located within the sub-basin under consideration (the S_i, P_i and D_i terms). The parameterisation of the model is flexible and can be study-area specific. The model is fitted by minimising the sum of squares for the difference in observed and estimated loads. In this study, P_i and D_i were assumed to be known and S_i was assumed to be a simple function of land use according to $S_i = (\beta_1 a_{1i} + \beta_2 a_{2i} + \beta_3 a_{3i})$. Here a_{1i}, a_{2i} and a_{3i} denote the area of agricultural land (arable land and pastures, forests and other land (mainly bogs and urban areas) in the sub-basins *i*, and β_1, β_2 and β_3 are unknown export coefficients (i.e. emission coefficients, unit-area loads) for the three land use categories.

Nutrients are normally retained temporally or permanently in watercourses. In the model retention is expressed as a summary expression for all hydrological and biogeochemical processes that may decrease or the transport or losses of nutrients. It can be parameterised by any empirical function. In this study, the retention is divided in two – retention in lakes and river retention (i.e. instream retention). Both types of retention can be expressed according to the following formula [6]:

$$R_i = 1 - \frac{1}{1 + \lambda_1 \times \text{drainage area}_i} \times \frac{1}{1 + \lambda_2 \times \dfrac{\text{lake area}_\text{i}}{\text{drainage area}_i}} \tag{2}$$

where λ_1 and λ_2 denote a non-negative parameter and R_i denotes the retention in the ith basin. The first part of the function reflects the in-stream retention whereas the second part reflects the retention in lakes and reservoirs.

Retention was parameterised using the simplest possible function (i.e. *fact*). It was assumed that retention in lakes was a function of the lake area divided by drainage area, and riverine retention a function of the drainage area.

Retention from an arbitrary sub-basin *m* to the river mouth (R_{mouth}) can be derived from:

$$R_{m,mouth} = 1 - \prod_{j=1}^{k} (1 - R_j) \tag{3}$$

where

$R_{m,\,mouth}$ = retention from the outlet of the sub-watershed *m* on the way to the mouth of the whole river;
k = number of sub-basins downstream sub-basin *m*;
R_j = the values of retention within the different sub-basin downstream the sub-basin *m*.

3. Results

One of the problems in estimating general emission coefficients (expressed as unit-area losses) for the whole country is the differences in flow rates (e.g., specific runoff) between 40-50 investigated sites (depends on a year). Another problem is that the difference in water runoff between sites also can vary greatly in different years as exemplified in Fig. 2. One can see that in some years the runoff is almost the same while in others the differences can be very high (e.g. years 2003, 2012). Therefore it was found necessary to adjust riverine loads in the MESAW for each year under investigation. Firstly, the average annual runoff was calculated by using the flow rates of all rivers in Estonia. Secondly, the flow rate coefficients for each river were calculated by dividing the average runoff by the river's runoff. Finally, the corrected loads were calculated by multiplying loads by the flow rate coefficients. With these procedures, it was assumed that the correlation between the emissions and runoff is linear. In Fig. 3 & 4 the dependency between the emission and runoff is shown for river Võhandu and river Jägala. Evidently, the correlation between the two variables is more or less linear.

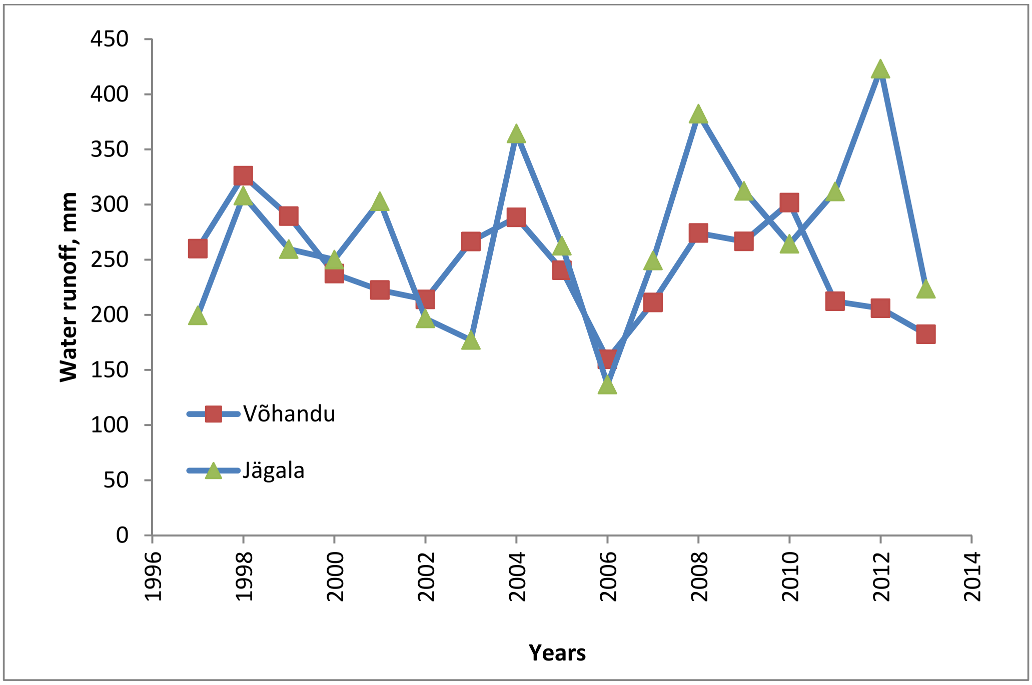

Fig. 2. Annual water runoff in rivers Võhandu (SE Estonia) and Jägala (N Estonia) in 1997-2013.

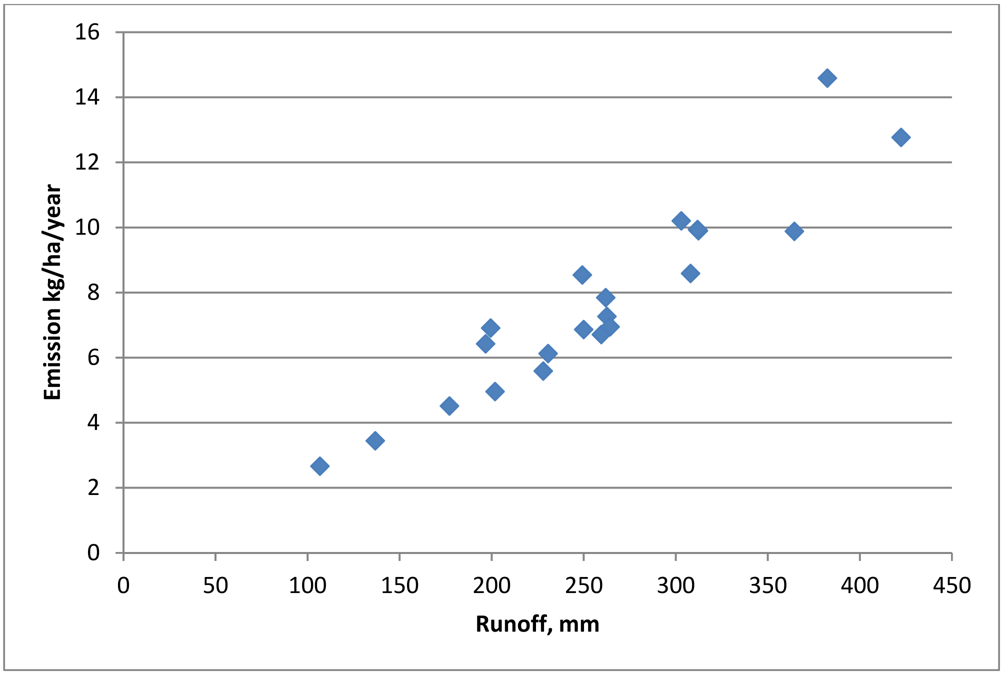

Fig. 3. Dependence between total nitrogen emission and water runoff (River Jägala).

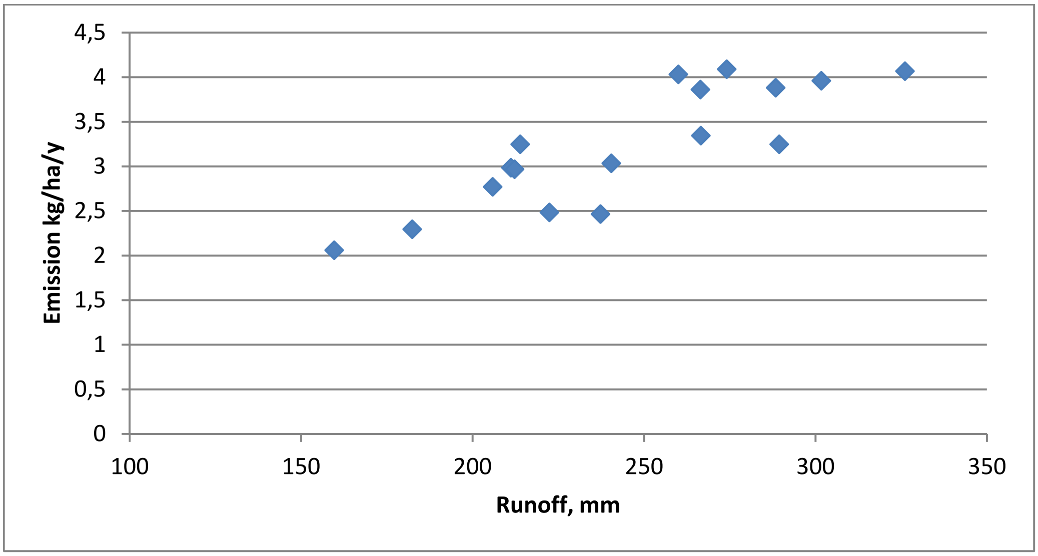

Fig. 4. Dependence between total nitrogen emission and water runoff (River Võhandu).

Source apportionment of total nitrogen loads using MESAW model was estimated for 3 different years (2007, 2008, 2011).

Three different land use categories were used for the estimations – arable land, drained peat soils and others (named natural areas) that included forest, pastures, natural grass lands, bogs. In Table 1 the modelling results for the whole Estonia are presented.

Table 1. Results of estimated total nitrogen emission coefficients for the 3 land cover classes for the whole of Estonia.

Year	Arable, kg/ha	Natural areas, kg/ha	Drained peat areas, kg/ha	Average water runoff, mm
2007	14.3	1.2	32.0	245
2008	24.9	2.8	35.6	409
2011	15.6	2.2	33.1	338

All the coefficients for all years were statistically significant ($p<0.05$). According to the results the highest unit-area loads for total nitrogen loads in 2007, 2008 and 2011 are from areas with drained peat soils. The results are somewhat controversial as according to water management plans it is expected that in Estonia most of the nutrient loads to rivers come from arable lands.

In the next step the MESAW model was used in a smaller area (Tallinn's drinking water catchment area) with more detailed measurements. Measurements of Tallinn Water Company were used as inputs for the model. Nitrogen concentrations were measured in 12 points from 12 to 52 times per year. The study area consists of ten sub-basins located in the river Pirita and two sub-basins located near river Pirita. Nitrogen load from animals to the waterbodies was estimated as 19 % of the total load from animals [7]. Modelling results of source apportionment in Tallinn catchment area are presented in Table 2.

Table 2. Results of estimated total nitrogen emission coefficients for the 3 land cover classes for the Tallinn catchment area.

Year	Arable, kg/ha	Natural areas, kg/ha	Drained peat areas, kg/ha	Average water runoff, mm
2007	24.6	2.7	32.1	249
2008	43.1	4.3	41.4	382
2011	17.5	3.8	40.0	311

All the coefficients for all years were statistically significant ($p<0.05$). Similar to the analysis above for the whole of Estonia, the results for the Tallinn catchment area showed that the unit-area losses for drained peat soils is significantly higher than for arable lands. Notable was that the emission coefficients for all land types are much higher in the Tallinn catchment area than for the whole Estonia (Table 1 & 2). One though have to bear in mind that Table 1 contains averaged values for the whole Estonia (quite large area with high differences in emission coefficients). Moreover, it is likely that the study area close to Tallinn exhibit more intensive agriculture and some extra sources of pollution (e.g. higher air deposition due to intensive transport). From the results it is evident that an extensive study for defying the sources of nitrogen in Estonia is necessary. At the moment it is believed that the main source is arable lands but different investigations have suggested that e.g. drained peat soils can be an additional remarkable source. In this sense the measures to reduce nutrient loads to waterbodies have to be carefully scrutinized.

From the modelling results it can be seen that the loads form arable lands in 2011 is substantially lower than in both 2007 and 2008. This might be linked with the last economic crisis as the usage of fertilizers decreased in Estonia during the same period [8]. This indicates that the emissions of nutrients from arable lands could be reduced with correct measures.

The comparison between modelled and measured loads in the smaller study area for 2011 are presented in Fig. 5. The correlation between the observed and modelled loads is more-or-less linear indicating that the calculated results are reliable.

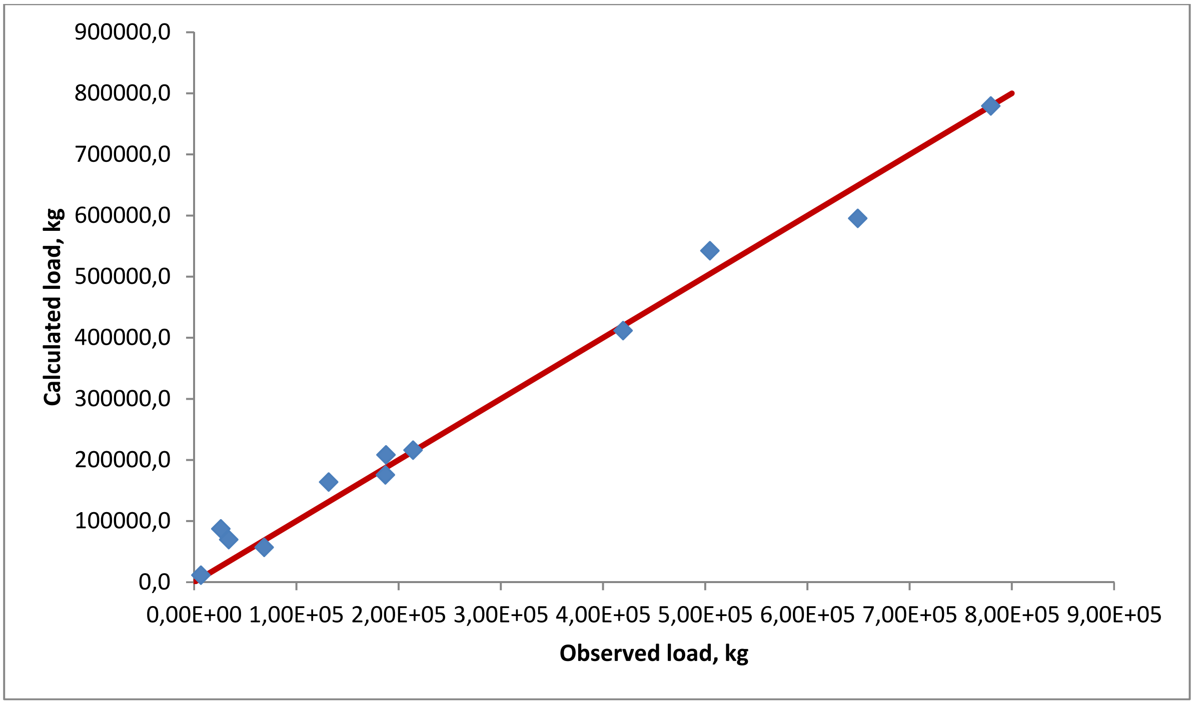

Fig. 5. Calculated vs. observed nitrogen loads for Tallinn catchment area.

4. Conclusions

A statistical model MESAW was used to investigate the emission coefficients of nitrogen in Estonia. This includes analysis of data on loads, point sources, land use types etc. Two studies were conducted to determine the emission coefficients for the whole Estonia and for a smaller study area near Tallinn.

- The MESAW model was able to estimate statistically significant ($p<0.05$) diffuse emission coefficients for arable land, drained peat soils and other land
- Diffuse emission coefficients of total nitrogen is highly correlated to the water runoff
- Unit-area losses from drained peat soils was estimated to vary between 32-41 kg/ha and up to 2.3 times higher than from arable land
- Unit-area losses from natural land was estimated to 1-4 kg/ha.

Comparison of emission coefficients of Estonia and Tallinn catchment area indicated that the coefficients can vary significantly even in a quite small country. Therefore it is suggested that the sources of nitrogen loads should be defined in a catchment area level rather than a country level. Additional measurements are needed to specify the emission coefficients in all areas of Estonia.

Acknowledgements

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