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Population Equivalence Based Discharge Criteria of Wastewater Treatment Plants in Estonia

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Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any academic degree.

/Raili Niine/

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Inimekvivalentidel põhinevad reoveepuhastite heitvee standardid Eestis

RAILI NIINE

TTÜ KIRJASTUS

"Boundaries don't protect rivers, people do."

Aristotle
Greek philosopher 384–322 BCE

CONTENTS

LIST OF PUBLICATIONS CONSTITUTING THE THESIS

The thesis is based on four publications in international peer-reviewed journals. The publications are referred to in the text as Paper I, Paper II, Paper III and Paper IV.

Paper I: Niine, R.; Loigu, E.; Pachel, K. (2013). Compliance of wastewater treatment plants in Järva county with the EU urban wastewater treatment directive and Estonian national requirements. European Scientific Journal, 3, 365-375.

Paper II: Niine, Raili; Loigu, Enn; Tang, Walter Z. (2013). Development of Estonian nutrient discharge standards for wastewater treatment plants. Estonian Journal of Engineering, 19, 152–168.

Paper III: Niine, Raili; Loigu, Enn; Pachel, Karin (2013). Distribution of Different Pollution Loads from Wastewater Treatment Plants and their Impact on Water Bodies in Estonia. International Journal of Energy and Environment, 7(2), 86-95.

Paper IV: Niine, R., Loigu, E., Pachel, K. (2012). Wastewater impact on the quality of waterbodies in Estonia. In: Advances in Environment, Computational Chemistry & Bioscience: 10th WSEAS International Conference on Environment, Ecosystems and Development (EED '12), Montreaux, Switzerland, 29-31 December 2012. (Ed.) Prof. S. Oprisan et.al. Montreaux, Switzerland: WSEAS Press, 2012, 175–180.

AUTHOR´S CONTRIBUTION TO THE PUBLICATIONS

Paper	Original idea	Study design and methods	Data collection and handling	Contribution to result interpretation and manuscript preparation	Responsible for result interpretation and manuscript preparation
I	RN	RN	MOE, RN	RN, EL, KP	RN
II	RN	RN	MOE, RN	RN, EL, WT	RN
III	RN	RN	MOE, RN	RN, EL, KP	RN
IV	RN	RN	MOE, RN	RN, EL	RN

RN- Raili Niine
EL - Enn Loigu
KP - Karin Pachel
WT - Walter Z. Tang
MOE - Ministry of the Environment

1. INTRODUCTION

1.1. Water management

Water is a prerequisite for life, and the most important natural resource. The quality of water bodies may be at risk due to eutrophication, acidification, and hazardous pollution. This in turn affects biological diversity and its conservation. Since water does not recognise national boundaries, coordinated and comprehensive water management is extremely important. In this study, the measures that are necessary to limit point-source pollution of surface water bodies are investigated. Ensuring good status of water bodies requires early stage preventive measures, as well as sustainable planning. Moreover, the status of water bodies depends on the quality of effluent discharged to the receiving water bodies, among other things.

1.2. Urban Wastewater Treatment Directive (UWWTD)

The Council Directive 91/271/EEC concerning urban wastewater treatment was adopted on 21 May 1991. Its objective is to protect the environment from the adverse effects of urban wastewater discharges and discharges from certain industrial sectors. It concerns the collection, treatment and discharge of domestic wastewater, mixture of wastewater, and wastewater from certain industrial sectors at EU level. To protect the environment from the adverse effects of the treated wastewater effluent, secondary or tertiary treatment in sensitive areas has to be implemented. Primary wastewater treatment is permitted in less sensitive areas. In addition, urban wastewater treatment directive regulates that each Member State must ensure appropriate treatment for industrial wastewater, regardless of whether the industry uses the public sewage system or its own treatment facilities, if the effluent is directly discharged to the receiving water bodies. The EU member states shall ensure that the WWTPs are built to comply with the directive requirements. They should be designed, constructed, operated and maintained to ensure sufficient performance under all normal local climatic conditions. Also, sludge generated from wastewater treatment shall be re-used whenever appropriate and is subject to general rules or authorisation. The directive emphasises the need for the constant monitoring of wastewater and receiving water bodies in order to take additional measures, if necessary.

The final UWWTD deadline for the transitional period was 31 December 2010 for Estonia. Moreover, for agglomerations with a pollution load more than 10,000 population equivalent (p.e.) the deadline was 31 December 2009. The transitional period was given mostly for planning, construction and operating public sewage systems and WWTPs as required in the directive.

1.3. Wastewater treatment requirements in Estonia

In Estonia, all water bodies are categorised as sensitive water bodies according to UWWTD. In other words, Estonian water bodies are sensitive to nutrients and have a high eutrophication risk. Therefore, all Estonian WWTPs have much higher treatment standards than most of the other European regions. Since Estonia is a country in the Baltic Sea region, the recommendations of the Helsinki Commission (HELCOM) must be taken into account in addition to the European Union directives. The HELCOM recommendations imposed much stricter requirements than UWWTD. One of the main issues covered by the Baltic Sea Action Plan is the further reduction of nutrient inputs in order to limit the eutrophication of water bodies. The most important HELCOM recommendations for wastewater treatment are recommendation no 28E/5 concerning municipal wastewater treatment and recommendation no 28E/6 concerning the on-site wastewater treatment of single family homes, small businesses and settlements up to 300 p.e. Estonia enforces the above-mentioned main requirements with the following acts and regulations: Water Act; Public Water Supply and Sewage Act; the Regulation of the Government of Estonia no 99, 29 November 2012 "The requirements of wastewater treatment and discharging waste and storm water to the recipient, the limit values for waste and storm water pollution indicators and the control measures of the compliance check" (RT I, 04/12/2012, 1); Regulation of the Government of Estonia no 171, 16 May 2001 "Water protection measures of sewer works" (RT I 2001, 47, 261); Regulation of the Government of Estonia no 57, 19 March 2009 "The criteria for designate agglomeration areas" (RT I 2009, 19, 125); Regulation of the Minister of Environment no 78, 30 December 2002 "Requirements of using sewage sludge in agriculture, landscaping and re-cultivation" (RTL 2003, 5, 48) and Regulation of the Minister of Environment no 34, 1 July 2009 "The measure conditions of "Development of water management infrastructure" (RTL 2009, 55, 811).

1.4. Balanced development of water management in the field of wastewater treatment

Sustainable water management is one of the key challenges today. Integrated water management has been a guiding principle in different development plans. Since watershed, receiving water body, urban wastewater treatment and sewer network are parts of an integrated whole, the balance between social, economic, technical and environmental aspects should be the key in water management (Péter, J, 2007). Therefore, different alternatives that help to find an optimal solution and help to answer how best to identify the best technical solution among several feasible alternatives (different ecological criteria and correlation between ecology and costs) must be evaluated (Starkl, et. al, 2009; Xenarios and Bithas, 2007; Zabel, et al., 2001). The integrated and comprehensive solution of environmental problems should take into account all potential adverse effects to determine the best solutions. In this study, the established wastewater treatment standards were analysed by assessing the wastewater impact on the receiving water bodies, WWTPs effectiveness and the accompanying socio-economic impact. Another aim of the study was to find the bottlenecks that may cause a setback for the balanced development of wastewater treatment in Estonia.

2. OBJECTIVES

The aim of this study was to assess the WWTPs effluent impact on receiving water bodies using treatment efficiency and socio-economic impacts in Estonia and, therefore, develop wastewater discharge criteria. The specific objectives were as follows:

1. To assess the treatment efficiency conformity of WWTPs to the Estonian and European Union requirements (**Paper I**)
2. To evaluate the existing national wastewater monitoring programme and the efficiency of the self-monitoring programme (**Paper I**)
3. To assess the cumulative impact of effluent and analyse the compatibility of the validated wastewater requirements in Estonia (**Paper I**)
4. To evaluate the WWTPs treatment efficiency, total pollution load due to different sizes of WWTPs and feasibility to implement stricter treatment requirements (**Papers II, III and IV**)
5. To evaluate socio-economic impacts with consideration to the environmental benefits for different alternatives (**Paper II**)
6. To develop optimal Estonian Nutrient Discharge Standards for WWTPs (**Paper II**)
7. To analyse wastewater effluent impacts on receiving water body quality and whether stricter wastewater treatment requirements are needed to protect Estonian water bodies (**Papers III and IV**)
8. To make recommendations for improving water management in Estonia (**Papers I, II, III and IV**).

ABBREVIATIONS AND TERMS

Agglomeration - an area where the population and/or economic activities are sufficiently concentrated for urban wastewater to be collected and conducted to an urban wastewater treatment plant or to a final discharge point

BOD_7- biochemical oxygen demand

C - concentration, (mg/l)

C_{TN} - concentration of total nitrogen, (mgN/l)

COD - chemical oxygen demand

ENS - Estonian national standards

HELCOM - The Baltic Marine Environment Protection Commission (Helsinki Commission)

MOE – Ministry of Environment

Population equivalent (p.e.) - a conventional unit of mean daily water pollution, caused by one person. The value of one population equivalent expressed by biochemical oxygen demand (BOD_7) is 60 grams of oxygen per day.

SS - suspended solids

TP - total phosphorus

TN - total nitrogen

WWTP - wastewater treatment plant

UWWTD - Council Directive 91/271/EEC concerning urban wastewater treatment

3. MATERIAL AND METHODS

During the study, 773 different WWTPs were analysed. Of these plants, 67 serve the agglomeration areas with a pollution load of 2,000 p.e. or more and all other WWTPs serve the agglomeration areas where the pollution load is less than 2,000 p.e. Estonia has a total of 59 agglomeration areas with a pollution load of 2,000 p.e. or more but all the WWTPs that serve these areas must comply with 2,000 p.e. or more agglomeration area requirements. The analysis is based on 2,249 sample results, which were taken from different WWTPs to analyse BOD_7, SS, TN, TP and COD concentrations of the discharge. In addition, 1,198 sample results were taken from the appropriate upper and lower courses of receiving water bodies from the WWTP effluent inlet.

The analysis on the wastewater samples was carried out in accredited laboratories in Estonia using standardised methodology SFS 5505:1988 for TN, EVS-EN ISO 6878:2004 for TP, ISO 5815-1:2003 for BOD_7, EVS-EN 872:2005 for SS and ISO 6060:1989 for COD. Additionally, qualified samplers who have been granted attestation took all the samples. All receiving water body samples consist of three samples – surface water sample before WWTPs effluent inlet to the receiving water body, surface water sample after WWTPs effluent inlet and WWTP effluent sample. BOD_7, SS, TN, TP and COD were also analysed for all the samples. For the upper portion of the water body, samples were taken approximately 500 m before the effluent inlet to the water body and the lower course sample was taken where wastewater is well mixed with surface water. The actual sampling location depended on the water body such as turbulence and water flow rate, etc.

3.1. WWTPs compliance criteria

The monitoring results were based on control sampling conducted by environmental authorities. The total pollution load is calculated using monitoring results and the actual flow rate of WWTP effluent from the National Environmental Register (MOE, 2009/1). The UWWTD only sets limit values for WWTPs with a pollution load more than 2,000 p.e. because it aims to establish minimum treatment requirements (European Community, 1991/2). The effluent limit values for WWTPs with a pollution load less than 2,000 p.e. were not regulated by these requirements. Separate criteria are used to assess the compliance of these WWTPs with the requirements. The common limit values given in the permits for the special use of water (MOE, 2009/2) for establishing the criteria for WWTPs with a pollution load less than 2,000 p.e. were used. Both UWWTD requirements and ENS are listed in Table 3.1. and 3.2., respectively (**Papers I, II, III and IV**).

Table 3.1. UWWTD Treated Wastewater Discharge Quality

Pollution indicator	Limit values, mg/l			
	<2,000 p.e.*	2,000-9,999 p.e.	10,000-99,999 p.e.	≥100,000 p.e.
BOD_7	25	25	25	25
COD	125	125	125	125
SS	35	35	35	35
TP	-	-	2	1
TN	-	-	15	10

* The Urban Wastewater Treatment Directive does not establish common criteria and only requires an appropriate treatment level. These criteria are developed by taking into account the aim of the directives and requirements given in the permits for the special use of water.

Table 3.2. Treated Wastewater Discharge Quality Criteria by the ENS

Pollution indicator	Limit values, mg/l				
	<500 p.e.*	500-1,999 p.e.*	2,000-9,999 p.e.	10,000-99,999 p.e.	≥100,000 p.e.
BOD_7	25	25	15	15	15
COD	125	125	125	125	125
SS	25	25	25	15	15
TP	-	2	1.5	1	1
TN	-	-	-	15	10

*Estonia did not establish common standards until 2013. These criteria are developed by taking into account the aim of the directives and requirements given in the permits for the special use of water.

To comply with the requirements, a minimum number of effluent samples are required each year, depending on the WWTP size. The compliance check for WWTPs with more than 2,000 p.e. is based on the principle that 3 monitoring results of 4 samples must be in conformity with the criteria as described in either Table 3.1. or Table 3.2. The WWTPs of less than 2,000 p.e. are in conformity with the requirements, if all quality indicators (the criteria in Table 3.1. or Table 3.2) are met in more than 50% of all samples. If the number of samples that confirm and the number of samples that do not confirm the criteria in Table 3.1. or Table 3.2. are equal, the compliance check would be based on the average monitoring results made by the water user.

3.2. Analyses of permissible pollution load

The actual pollution loads were calculated on the basis of the actual flow rate of wastewater and the monitoring results of effluent. Permissible pollution loads have been calculated using the actual flow rate of wastewater and established Estonian national limit values of pollution indicators (Table 3.3.). The flow rates of wastewater used were obtained from the national database kept by the Estonian Environment Information Centre (**Papers I, II, III and IV**).

Table 3.3. Estonian National (EE), European Union (EU) and HELCOM (HE) Wastewater Discharge Criteria

Legislation	BOD_7, mgO_2 /l	COD, mgO_2/l	SS, mg/l	TP, mgP/l	TN, mgN/l
≥100,000 p.e.					
EE	15	125	15	1	10
EU	25	125	35	1	10
HE	15	-	-	0.5	10
10,000-99,999 p.e.					
EE	15	125	15	1	15
EU	25	125	35	2	15
HE	15	-	-	0.5	15
2,000-9,999 p.e.					
EE	15	125	25	1.5	-
EU	25	125	35	-	-
HE	15	-	-	1	30%
500-1,999 p.e.[1]					
EE	25	125	25	2	-
EU	25	125	35	-	-
HE*	25	-	-	2	35
<500 p.e. [1]					
EE	25	125	25	-	-
EU	25	125	35	-	-

[1] The EU does not establish common standards and Estonia did not establish common standards until 2013. These standards are developed by taking into account the aim of directives and requirements given in the permits of water special use.

HE**	*Alternative 1*: the requirements based on emissions per capita need not apply where it can be shown that an on-site WWTP results in a maximum concentration of BOD_5 of 20 mg/l, P_{tot} 5 mg/l and TN_t 25 mg/l in the effluent of the WWTP. *Alternative 2*: the requirements based on emissions per capita need not apply where it can be shown that an on-site WWTP using the Best Available Technology (BAT) is installed and operated so that the treatment results in a maximum concentration of BOD_5 of 40 mg/l and 150 mg/l COD in the effluent of the WWTP.

*300–2,000 p.e.; **less than 300 p.e.

The effluent TP limit value for WWTPs with pollution loads of 500-2,000 p.e. set in special water permits of 2 mg/l (Table 3.3.) was also used for WWTPs with pollution loads between 300 and 500 p.e. For WWTPs with loads less than 300 p.e., a weaker socio-economic situation was considered in the study; therefore, a lower limit value of 3 mg/l was the basis for the TP permissible pollution load calculations. For WWTPs below 10,000 p.e., the permissible pollution load is calculated using 30% of TN removal, since 30% of the TN removal is achievable if the biological treatment process functions normally and operates properly without enhanced nitrogen removal (such as nitrification/denitrification process). The difference between the actual and permissible pollution load shows how much it is possible to reduce the total pollution load under conditions in which all WWTPs are in compliance with the established requirements.

4. THE STUDY NOVELTY

The study analyses the impact of discharge from WWTPs of different sizes on the environment. The study is unique as it was first time the cumulative impact of different sized WWTPs on the environment was analysed in Estonia, using state-controlled monitoring results as well as self-monitoring results for comparison**.** Also, during this study, the above normative pollution load to obtain comprehensive information regarding the status of WWTPs was analysed. This was done to obtain basic knowledge on whether the established wastewater treatment standards are in conformity with the required investments and exploitation cost of WWTPs, while taking into account that the impact of WWTPs on the environment must be minimal**.** Additionally, pollution load reduction is assessed according to its capital requirements and socio-economic impacts in this study. Also, it was first time to analyse the effectiveness of WWTPs using individual sample results methodology instead of annual average results. The difference between the assessment methodologies of the compliance of WWTPs with the requirements was considerable **(Papers I, II, III and IV)**.

5. RESULTS APPROBATION

10th WSEAS International Conference on Environment, Ecosystems and Development (EED '12), Montreaux, Switzerland, 29-31 December 2012. Oral presentation: **Niine, R**., Loigu, E., Pachel, K. Wastewater impact on the quality of waterbodies in Estonia.

6. RESULTS AND DISCUSSION

6.1. WWTPs efficiency and state of play

The study analyses the impact of different sized WWTPs on the environment. The average efficiency of the WWTPs (using BOD_7, TP, TN, SS and COD concentrations) in 2008 was 48% according to the Estonian national requirements and 65% according to the UWWTD requirements **(Paper III)**. The results show that the biggest hot spot is TP compliance. The average TP compliance was only 44%; at the same time, BOD_7 and TN average compliance was 69% and 80%, respectively, using ENS **(Paper III)**. TN removal is not a problem for WWTPs with pollution loads below 2,000 p.e. and also quite a good compliance rate is evident for WWTPs with pollution loads of 2,000-10,000 p.e.

A more comprehensive compliance check was made in Järva County in the area of Estonian nitrate vulnerable zone according to European Nitrates Directive. There were 21 urban WWTPs that do not belong to the directive, which constitutes 42% of all WWTPs covered in this study. In 2008, 59 samples were taken from 28 different WWTPs to assess the compliance of Järva County WWTPs with the UWWTD requirements. 18 treatment plants (64.3%) were in compliance. Of the WWTPs with pollution loads more than 2,000 p.e., only Paide WWTP met the requirements. The compliance check to ENS was based on the 83 samples that were taken from 47 different WWTPs. 23 WWTPs (48.9%) were in compliance with the requirements. Separately analysed monitoring results for the urban WWTPs that belong within the scope of the directive and the WWTPs outside the scope of the directive are given in Table 6.1 **(Paper I)**, where the average effluent concentrations in mean ($\bar{x}$) and median (Me) of WWTPs in Järva County are shown.

Table 6.1. Average concentrations of the effluent of WWTPs in Järva County

	SS, mg/l		BOD_7, mgO_2/l		TN, mgN/l		TP, mgP/l		COD, mgO_2/l	
	$\bar{x}$	Me	$\bar{x}$	Me	$\bar{x}$	Me	$\bar{x}$	Me	$\bar{x}$	Me
Urban WWTPs belong to the scope of the UWWTD	17.7	14.0	24.7	14.0	15.3	8.4	3.7	3.4	85.1	70.0

Urban WWTPs outside the scope of the UWWTD	22.6	18.0	54.7	22.0	28.7	9.9	4.8	4.2	163.3	80.0
Results difference (%)	21.5	22.2	54.8	36.4	46.7	15.2	23.3	19.0	47.9	12.5

The study results show that average effluent concentration is in compliance with the UWWTD requirements, except TP results, because the UWWTD does not provide TN and TP removal requirement for WWTPs with a pollution load less than 10,000 p.e. Table 6.1 represents only two (Paide and Järva-Jaani) WWTPs effluent results with a pollution load more than 10,000 p.e., because the remaining 44 treatment plants have pollution loads less than 10,000 p.e. Comparing the average concentrations of the effluent of WWTPs that belong within the scope of the UWWTD and are added to the WWTPs results that do not serve the agglomeration, the average of the results differs up to 55% **(Paper I)**.

The high content of phosphorus causes problems in the recipient waterbodies, resulting in algae blooms and excessive plant growth. Figure 6.1 indicates phosphorus cumulative distribution; each point on the figure characterises a single WWTPs average result based on 1-4 monitoring samples.

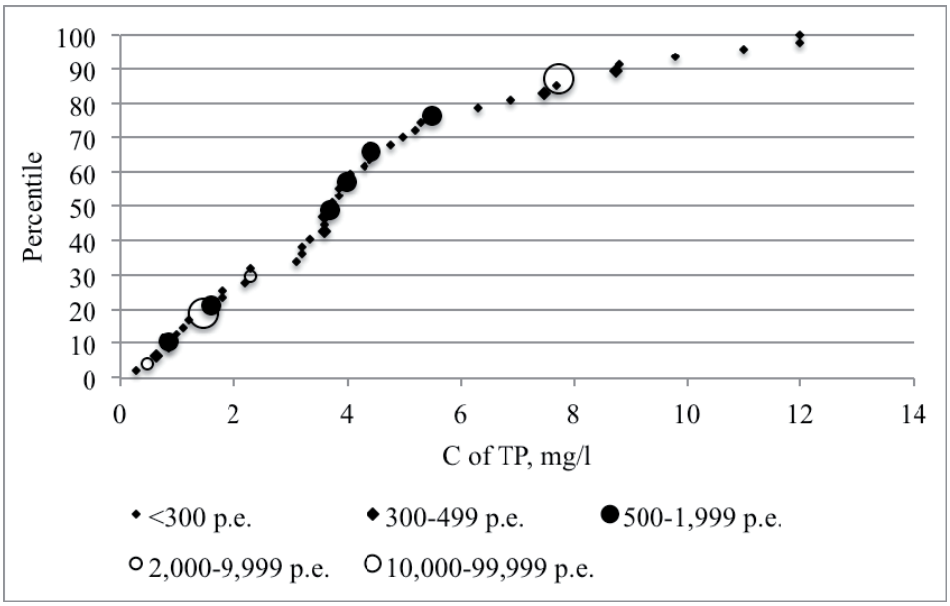

Figure 6.1. Percentile values of TP of different sized WWTPs in Järva County

The 50-percentile value of TP for all types of WWTPs is 3.7 mg/l; the outlet concentrations of only 12 WWTPs are below 2.0 mg/l. To improve the ecological status of small rivers, it is necessary to reduce TP values from WWTP effluents.

6.2. Distribution of the pollution load due to discharge from WWTPs

Using the study results that reflect 774 different sized WWTPs effluent analyses, the total pollution load discharged into the environment in terms of BOD_7, TP and TN is given in Table 6.2 **(Paper III)**.

Table 6.2. Total pollution load (tons per year) in 2008.

Pollutant	Pollution load (t/y)	
	≥ 2,000 p.e. WWTPs	< 2,000 p.e. WWTPs
TP	74.84	29.60
TN	981.51	194.42
BOD_7	687.07	404.92

As Table 6.2 shows, WWTPs with pollution loads of 2,000 p.e. or more have the greatest impact as these plants together form 72% of the entire TP pollution load and only 28% of the TP pollution load comes from WWTPs with less than 2,000 p.e. Similar results are also for BOD_7 and TN, and the biggest pollution load on the environment comes from the WWTPs with pollution loads of 2,000 p.e. or more. WWTPs with less than 2,000 p.e. have the highest impact in the BOD_7 pollution load, as these plants form 37% of the entire BOD_7 pollution load discharged into the environment. The origin of BOD_7 and TN pollution load is given in Figure 6.2 **(Paper III)**.

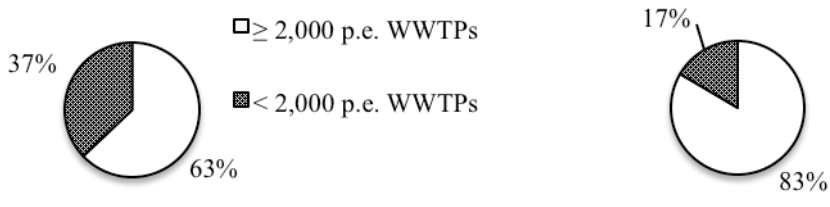

Figure 6.2. Origin of BOD_7 (left) and TN (right) pollution load

The above normative pollution load was analysed to obtain comprehensive information regarding the status of WWTPs. This was to obtain background knowledge on whether the established wastewater treatment standards are in compliance with the required investments and exploitation cost of WWTPs, while minimising the impact of WWTPs on the environment. The study results show that it is essential to bring WWTPs with a pollution load of 2,000 p.e. into focus and due to the fact that these plants have the biggest impact on the environment **(Papers I, II, III and IV)**. On the other hand, the water quality of discharge from these WWTPs are not in compliance with the established wastewater treatment standards, which cause water bodies to be overloaded with TP and biodegradable organic matter **(Papers I, III and IV)**. Different sizes of WWTPs effluent pollution loads, discharged to the recipient, were assessed to determine the cumulative impact on the environment. Figures 6.3-6.5 show the TP, BOD_7, and TN actual and permissible pollution loads discharged into the environment by 774 WWTPs **(Paper III)**.

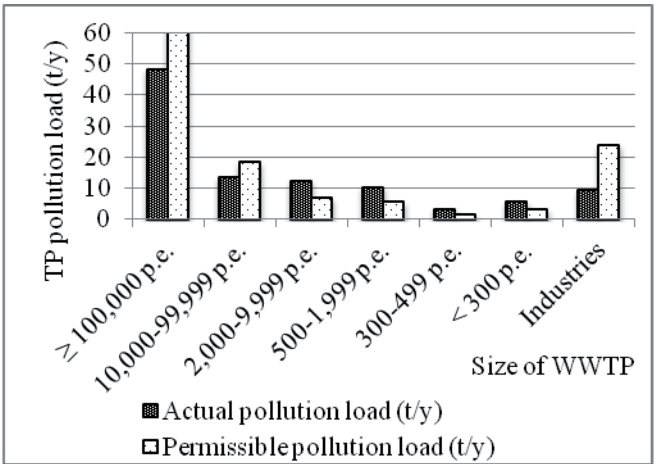

Figure 6.3. TP actual and permissible pollution load distribution

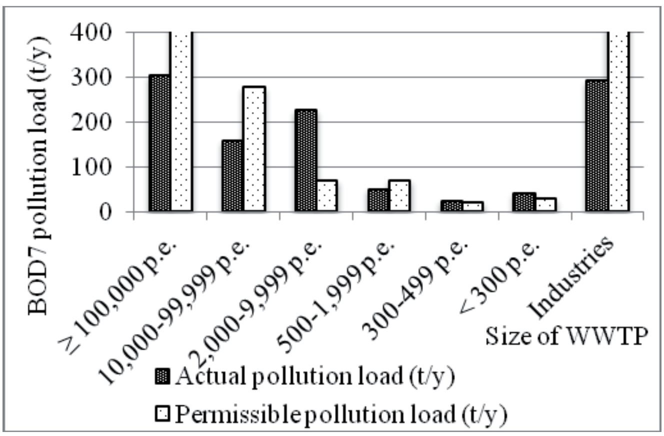

Figure 6.4. BOD_7 actual and permissible pollution load distribution

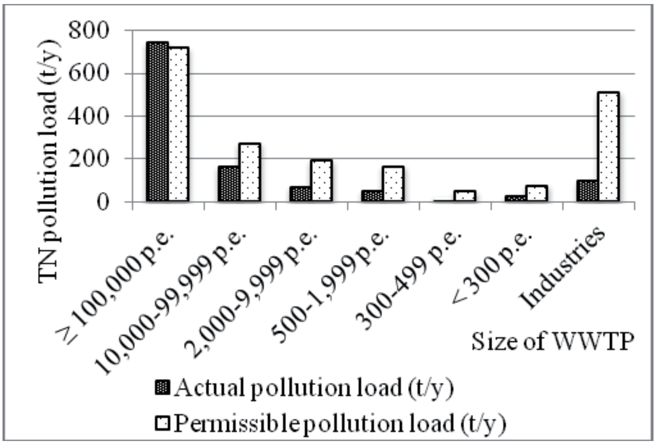

Figure 6.5. TN actual and permissible pollution load distribution

This study calculated the TP over loads from the WWTPs categories that do not comply with the permissible pollution load. It was concluded that it is possible to reduce the actual pollution load in terms of TP by at least 14.8 tons per year: 5.6 tons from WWTPs with pollution loads of 2,000-10,000 p.e.; 5 tons from WWTPs with pollution loads of 500-2,000 p.e.; 1.9 tons from WWTPs with pollution loads of 300-500 p.e., and 2.3 tons from WWTPs with pollution loads less than 300 p.e. In comparison, HELCOM has given the reduction target for Estonia in term of TP 348 tons per year (HELCOM, 2013). Taking into consideration the real effluent pollution load and diffuse pollution load, the HELCOM reduction target seems to be quite unrealistic.

Also, it is possible to reduce actual pollution loads in terms of BOD_7 by at least 171 tons per year: 156 tons from WWTPs with pollution loads of 2,000-10,000 p.e.; 3 tons from WWTPs with 300-500 p.e., and 12 tons from WWTPs with less than 300 p.e. Additionally, it is possible to reduce actual pollution load in terms of TN by at least 22.7 tons and all the TN overload comes from WWTPs with pollution loads of 100,000 p.e. or more **(Paper III)**.

6.3. WWTPs effluent impact on the water bodies

Considering the effluent pollutant concentrations of WWTPs, the impact of every single WWTP effluent on certain water body quality was analysed. The average concentrations of WWTPs effluent pollutants show that it is important to analyse the wastewater impact on water bodies, while considering whether a single WWTP is in compliance with the ENS.

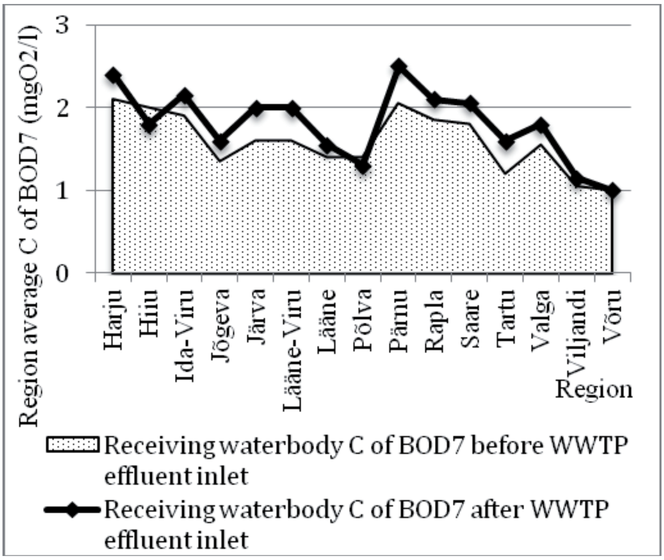

Figure 6.6. WWTP effluent average BOD_7 impact on the receiving water body in Estonia

Figure 6.6 shows that the WWTPs effluent inlet impacts the receiving water body quality. The water quality of the receiving water body deteriorated by approximately 13% since the WWTP effluent inlet to the receiving water body **(Papers III and IV)**.

Taking into account the results in Figure 6.6 and even if we consider that the WWTP effluent adversely affects the receiving water body, the absolute values show that the main effluent impact is not significant enough to change the status of the receiving water body. The water body has a good status in terms of BOD_5, if the BOD_5 concentration varies from different watercourses from 1.8-3.5 mgO_2/l (MOE, 2009). Figure 6.6 shows that the water bodies' average BOD_7 concentrations vary after WWTP effluent discharge from 1.0-2.5 mgO_2/l, which do not exceed the limit values established by the legal document. Therefore, we may conclude that BOD_7 is not the biggest problem for the quality of Estonian water bodies. However, the biggest part of BOD_7 overload comes from WWTPs with pollution loads of 2,000-10,000 p.e. and, additionally, the small WWTPs (below 500 p.e.) are largely not in compliance with the BOD_7 removal requirements, although the total pollution load from these plants is marginal **(Paper III)**.

The study unexpectedly shows that although WWTP effluent TP abundance has huge adverse effects on receiving water bodies, TN impact is nevertheless even smaller than BOD_7 impact and the quality of the receiving water body is approx. 9% deteriorated in comparison results before and after the effluent inlet to the water body. Therefore, we can admit that Estonian water bodies are first and foremost P-sensitive and also, according to the WWTPs treatment levels, TN removal is not a bottleneck problem for Estonian WWTPs **(Papers I, II, III and IV)**.

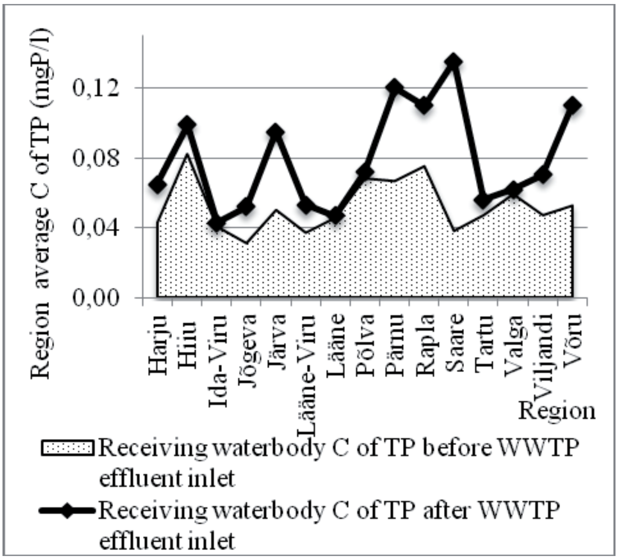

Figure 6.7. WWTP effluent average TP impact on the receiving water body in Estonia

Figure 6.7 shows that the WWTP effluent TP concentration has much a higher impact on the water body than BOD_7 concentration. The study shows that the receiving water body quality has deteriorated by as much as 52% since the WWTP effluent inlet to the water body. The TP values show that there is a strong impact on the status of the receiving water body **(Papers III and IV)**. The water body has a good status in terms of TP, if TP concentration is between 0.04-0.08 mg/l (MOE, 2009). Figure 6.7 demonstrates that the average TP concentrations of water bodies vary after WWTP effluent discharges from 0.04-0.14 mg/l. The TP concentration between >0.1-0.12 mg/l means that the water body status is poor and below 0.12 mg/l the water body status is bad (MOE, 2009).

6.4. Socio-economic impact of stricter discharge standards

Socio-economic analysis was made using Järva County WWTPs data. Costs for nitrogen removal to achieve 35 mgN/l (HELCOM recommendation) were estimated and are summarised in Figure 6.8. Figure 6.8 suggests that WWTPs that are discharging less pollution load to the receiving water bodies require higher investments to achieve TN limit concentration of 35 mg/l. WWTPs with a pollution load less than 10 000 p.e. have significantly higher TN load of the influent than WWTPs with a pollution load more than 10 000 p.e. Therefore, at least 40% of reduction of TN is required for WWTPs with a pollution load of 2,000 to 10 000 p.e., and for 300 to 2,000 p.e., about 60% of reduction of TN and less than 300 p.e. up to 67% of reduction. However, for WWTPs with a pollution load less than 500 p.e., TN reduction, and the amount of investments are not comparable. It should be noted that the reduction is calculated as maximum reduction, on condition that there is no existing nitrogen removal process. The actual reduction of the TN pollution load may be up to 30% less than indicated in Figure 6.8 because the existing biological treatment processes can remove up to 30% of TN **(Paper II)**.

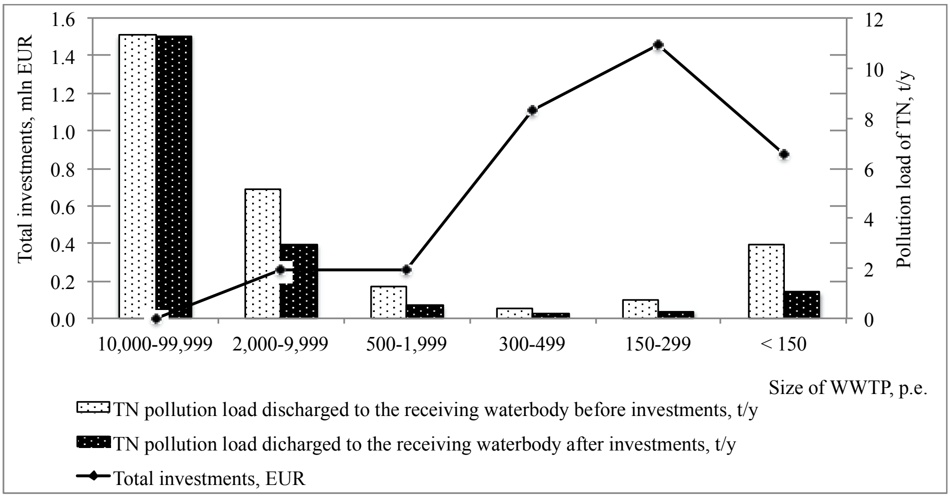

Figure 6.8. Pollution load of TN before and after introducing stricter limit values and additional investments

The socio-economic impact for using stricter requirements of TP given in Table 3.3 (HELCOM) is shown in Figure 6.9. It shows that the stricter phosphorus requirements do not lead to the very high investment needs. Investment need is estimated by assuming that WWTPs with a pollution load less than 2,000 p.e. have no chemical and biological phosphorus removal. When a WWTP currently has chemical phosphorous removal then the additional investments may not be necessary. Several studies show that phosphorous reduction is achievable even without any specific phosphorous removal strategy if the optimum dose of chemicals is used (Wang, et. al., 2006; Dueňas, et. al., 2003). WWTPs with the pollution load 2,000 p.e. or more must apply phosphorus removal according to the existing treatment requirements. Therefore, assessment of investments takes into account that these plants apply the chemical treatment of phosphorus. If these plants currently apply both chemical and biological phosphorus removal, the investment needs will be up to 90% less **(Paper II)**.

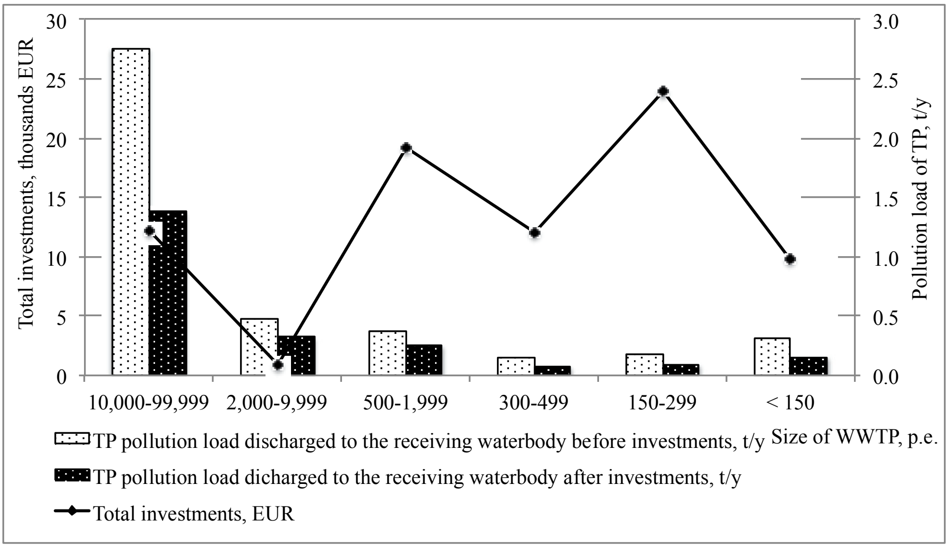

Figure 6.9. Pollution load of TP before and after introducing stricter limit values and additional investments

6.5. New wastewater discharge standards

Different sizes of WWTP pollution load discharged to the recipient were evaluated and additional investments required and environmental benefit were analysed. To compare the effluent pollutant load of WWTPs of less than 2,000 p.e. with those more than 2,000 p.e., the load from WWTPs with less than 2,000 p.e. is very small. However, taking into account the amount of TP given in Table 6.2 and Figure 6.3, and the socio-economic impact of implementing stricter requirements for phosphorus removal and also recipient sensitivity of phosphorus (Figure 6.7), it is important to impose TP limit concentration of 2 mg/l for WWTPs between 300 to 2,000 p.e. Accordingly, the TP reduction requirement is reasonable for WWTPs with a pollution load more than 300 p.e. On the other hand, the limit concentration for TP should not be stricter than 2 mg/l for WWTPs between 300 and 2,000 p.e. according to the amount of phosphorus pollution load **(Paper II)**.

Based on Figure 6.8 and the socio-economic impact, the implementation of C_{TN} of 35 mg/l for WWTPs with a pollution load less than 500 p.e. would be infeasible from the point of economical and environmental aspects. Through implementation of C_{TN} of 35 mg/l for WWTPs with a pollution load less than 500 p.e., the water service price will rise between 0.35 to 0.54 EUR/m^3, while a smaller quantity of TN reaching the water body has marginal importance in comparison to the TN total pollution load reaching the water body. The great investment difference between different size of plants is the fact that for WWTPs with a pollution load of more than 500 p.e. TN removal will be achievable by improving the existing technologies, but for WWTPs less than

500 p.e. it will only be possible to achieve the TN level of 35 mg/l for the construction of a new WWTP. Therefore, the implementation of C_{TN} 35 mg/l for WWTPs with a pollution load less than 10,000 p.e. is only justified if the concentration of 35 mg/l is used for WWTPs with a pollution load from 500 to 9,999 p.e. and the reduction rate of 30% or C_{TN} of 60 mg/l is used for WWTPs between 300 and 499 p.e., which can be achieved as a result of properly operated biological treatment processes without enhanced nitrogen removal **(Paper II)**.

Based upon the above analysis, new wastewater discharge standards, developed during this study, are given in Table 6.3.

Table 6.3. New wastewater discharge standards

Pollution indicator	Limit concentration, mg/l					
	<300 p.e.	300-499 p.e.	500-1,999 p.e.	2,000-9,999 p.e.	10,000-99,000 p.e.	≥100,000 p.e.
BOD_7	25	25	25	15	15	15
COD	125	125	125	125	125	125
SS	25	25	25	25	15	15
TP	N/A	2	2	1	0.5	0.5
TN	N/A	60	35	35	15	10

7. CONCLUSIONS AND RECOMMENDATIONS

In Estonia, much effort has been devoted to reducing the anthropogenic loads of TN and TP to water bodies, in terms of upgrading the existing WWTPs and building new WWTPs with higher nitrogen and phosphorus removal. The UWWTD does not impose any specific effluent limit values for WWTPs with a pollution load less than 2,000 p.e. Nevertheless, the effluent impact of WWTPs on the water bodies is considerable. Therefore, the criteria for a compliance check for these WWTPs have been developed in this study. However, when assessing the compliance of WWTPs with the ENS, it must be acknowledged that the national requirements are much stricter than the WWTPs can actually accomplish. Due to the total pollutant load and origin of the above normative pollution load, it is imperative to address the priority of WWTPs with a pollution load of more than 2,000 p.e., since these plants represent about 80% of the total WWTPs pollution load and these treatment plants also have the biggest impact on the above normative pollution load because of the non-compliance treatment level **(Papers I, III and IV)**.

Using total pollution loads and permissible pollution load calculations, it is possible to reduce the TP pollution load that is discharged into the environment by at least 14%, the BOD_7 pollution load by at least 16%, and the TN pollution load by at least 2% **(Paper III)**. The study indicates that due to non-compliance, WWTPs will cause rivers to overload with nutrients. The reasons for non-compliance have been largely due to a lack of purification capacity and operational and maintenance problems. Furthermore, quite common problems include technical mistakes in construction, significant under loading or overloading due to big variability of the inputs, frequently in small agglomeration areas the type of WWTP does not fit with the local conditions, small WWTPs operators lack knowledge and experience, necessary know-how and training, and water companies lack finances for investments. Also, water consumption in the last 15 years has significantly decreased due to the high water price; therefore, the concentration of pollutants in the wastewater is much higher, which makes the treatment more complicated and advanced technology is required **(Paper III)**. To improve the WWTPs operators' know-how and guarantee WWTPs operating properly, it is necessary to change the regulation so that the WWTPs operators' training and undergoing an operator's course must be mandatory rather than voluntary. Therefore, it is necessary to establish a national training centre to guarantee a consistently high level of training throughout the country.

In Estonia, the effluent inlets of WWTPs have the biggest adverse effect in terms of TP content in receiving water bodies. The study results show that after the effluent inlet to the water body, the quality of the receiving water body will deteriorate by approximately 52% in terms of TP concentration. Other contaminants like TN and BOD_7 do not have such a significant adverse effect on the receiving water body and the water quality may deteriorate 9-13% in terms of TN and BOD_7 concentrations, respectively **(Papers III and IV)**. In addition, the study shows that to minimise the adverse effects of effluent from WWTPs, it is not directly necessary to establish stricter treatment requirements, because it was apparent that the greater adverse effect was in districts where the WWTP treatment level was not in compliance with the validated requirements. Therefore, we can assume that the adverse effect of effluent on receiving water bodies will reduce considerably after renovation of these WWTPs, or at most at WWTPs outlets. The biggest problem is TP removal efficiency because only 44% of all WWTPs effluent concentrations are in compliance with the established standards in terms of TP **(Paper III)**.

If the socio-economic consequence is considered, stricter phosphorus requirements do not necessarily lead to very high investment needs **(Paper II)**. Implementing stricter wastewater treatment requirements means higher water service price for the population. At the same time, the study shows that to limit eutrophication, nitrogen and phosphorus concentrations of WWTP effluent discharged must be reduced. Therefore, nutrient effluent standards for WWTPs with the pollution load more than 300 p.e. are needed for environmentally and economically reasons **(Paper II)**. More stringent requirements than is reflected in this study would not be proportionate to the environment effect and does not guarantee comparable pollution load reduction to the investments for WWTPs. Also stricter wastewater treatment requirements than is given in this study may reduce accessibility of water service due to high water price.

The study shows positive feedback in terms of the total pollution load discharged into the environment. Using results from all 774 WWTPs, we can admit that the total pollution load in all contaminants discharged into the environment is much lower than the permissible pollution load that is calculated using established wastewater standards and actual effluent flow rate **(Paper III)**. Of course, if we studied the pollution load of different sized WWTPs separately, we would find that different sized WWTPs have different impact scales and, therefore, it is possible to reduce the total pollution load discharged into the environment in all pollutants and in all WWTP categories. Nonetheless, the cumulative impact of WWTP effluent is not significant although many WWTPs do not comply with the established requirements. If we consider the fact that many WWTPs are not in compliance with the established requirements, the analysis allows us to conclude that many WWTPs marginally exceed the limit values and WWTPs that are in compliance with the established requirements discharged notably less pollution into the environment than is actually permitted according to the established standards because total pollution load discharged into the environment is lower than the total permissible pollution load. Despite this, there are now several activities being implemented to reduce the significant inputs of organic pollutants and nutrients into water courses in Estonia. In recent years, important efforts to reduce the phosphorus load have been put into the upgrading of existing WWTPs as well as the construction of new higher efficient WWTPs in terms of phosphorus removal, together with the renewal of existing sewers and building new ones in order to connect more residential areas to public WWTPs.

Considering the fact that most of the Estonian WWTPs are in a renovation phase at the moment, it would be necessary to analyse the WWTPs effluent contaminants and nutrient ratio following the renovation of these WWTPs and also re-evaluate their compliance in 2014-2015. After that, it will be possible to compare the results before the WWTPs renovation phase with data collected from 2014-2015 after the renovation of the WWTPs.

At the same time, it is essential to make crucial changes in legislation to improve the national monitoring programmes and data collection system. According to the national wastewater monitoring programme, the measurements of water discharge in WWTP outlets and mixed river profile are not included at all. This is essential for calculating the actual wastewater load and its impact in low-flow rate periods. Therefore, legislation ought to be improved so that the monitoring frequency could depend on WWTP size, together with the condition of the WWTP and the status of the receiving water body. As this study shows, the self-monitoring system of the operators is not reliable enough to assess the actual status of WWTPs and the WWTP effluent impact on the receiving water bodies. The state-controlled WWTPs effluent monitoring results show, the monitoring results differ as much as 25% between national and self-monitoring results **(Paper I)**; therefore, it is not suitable to mix these data. As a result, self-monitoring results do not reflect the actual WWTP situation due to the low reliability of the monitoring results. In addition, national monitoring frequency and scope are not representative enough to make comprehensive conclusions. Therefore, the existing monitoring system should be improved so that all monitoring goes under state-control as well as establishing more frequent national monitoring. This will abolish the existing double-system, improve data reliability and give more adequate information about the status of water bodies.

In summary, the study shows that:

1) The biggest impact on water bodies are WWTPs that have a pollution load more than 2,000 p.e. The pollution load bigger than 2,000 p.e. WWTPs discharge to the receiving water bodies about 80% of the total pollution load;
2) WWTPs less than 2,000 p.e. have the highest impact in terms of TP. WWTPs with a pollution load of 2,000 p.e. and more have the highest impact in terms of BOD_7 and TP;

3) WWTPs self-monitoring results differ from the national monitoring results; therefore, the monitoring system needs essential changes;
4) WWTPs will cause rivers to overload with nutrients due to non-compliance with the established standards; despite that, harmonised national wastewater standards, found during this study, are needed according to the socio-economic assessment results;
5) WWTPs effluent TN requirement of 35 mg/l is not appropriate for WWTPs below 500 p.e., taking into account the amount of investments and TN pollution load reduction after investments. For WWTPs with a pollution load less than 500 p.e., the TN reduction and the amount of investments are not comparable;
6) It is recommended that more complex studies should be conducted in Estonia to analyse the cumulative impact on environmental processes.

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ABSTRACT

The main objective in water management is to achieve the good status of water bodies. One of the most important point sources of pollution in water bodies is wastewater treatment plant (WWTP) due to wastewater's negative effect on the quality of water bodies. The urban wastewater treatment directive (UWWTD) is the main document to regulate wastewater treatment at EU level. In Estonia, much effort has been devoted to reducing the anthropogenic loads of total nitrogen (TN) and total phosphorus (TP) to water bodies, in terms of upgrading the existing WWTPs and building new high-grade plants with nitrogen and phosphorus removal. Nevertheless, the effluent impact of WWTPs on the water bodies is considerable.

Monitoring results and total pollution load of effluent discharged to the receiving water body were used to assess the treatment level of WWTPs, analyse what kind of WWTPs have the biggest impact on the receiving water bodies and the need to establish higher treatment requirements in Estonia. Also, during this study, research was conducted into what kinds of wastewater pollutants have the greatest adverse effect on water bodies and what kind of steps Estonia needs to take to improve this.

WWTPs with a more than a 2,000 population equivalent (p.e.) should be stringently regulated to guarantee their compliance with the requirements, because WWTPs with more than 2,000 p.e. count for about 80% of the total pollution load. A pollution load from WWTPs of less than 2,000 p.e. on the receiving water bodies is marginal; however, it is also essential to analyse the cumulative impact of the pollution load from these kinds of WWTPs. If we consider the fact that many WWTPs are not in compliance with the established requirements (using every single wastewater sample results according to the UWWTD methodology instead of annual average results for compliance check), the analysis refers that many WWTPs marginally exceed the limit values and also WWTPs that are in compliance with the established requirements discharged notably less pollution into the environment than is actually permitted according to the established standards; therefore, the total pollution load discharged into the environment is lower than the total permissible pollution load in all pollution indicators.

The study results show that the effluent inlets of WWTPs have the biggest adverse effect in terms of TP content in receiving water bodies. The analyse shows that after the effluent inlet to the water body, the quality of the receiving water body will deteriorate by approximately 52% in terms of TP concentration.

During this study, WWTPs pollution load reduction is assessed according to its capital requirements and socio-economic impacts. WWTPs treatment efficiency, total pollution load coming from different size of treatment plants and feasibility for stricter treatment requirements and accompanying socio-economic impacts are evaluated with consideration to environmental benefits brought by the investment. New limit values for small-scale (below 2,000 population equivalent) treatment plants were proposed.

In the context of the study, several suggestions were also made for state authorities to improve the regulations of water management; for instance, wastewater discharge standards, wastewater and receiving water bodies monitoring requirements, the methodologies for data collection and analyses to obtain more reliable information about the status of the water's quality, and therefore enable to take into use necessary measures at the right time and at the right place.

KOKKUVÕTE

Inimekvivalentidel põhinevad reoveepuhastite heitvee standardid Eestis

Veemajanduse põhieesmärk on saavutada veekogude hea seisund. Üks olulisemaid veekogude punktreostusallikaid on reoveepuhastid heitvee negatiivse mõju tõttu. Euroopa Liidu kõige olulisemaks heitvett reguleerivaks dokumendiks on asulareovee puhastamise direktiiv. Eestis on tänaseks palju vaeva nähtud vähendamaks üldlämmastiku ja üldfosfori antropogeenset koormust veekogudele, kuna on ajakohastatud olemasolevaid reoveepuhasteid ning ehitatud täiesti uusi kõrgetasemelisi lämmastiku- ning fosforiärastusega puhasteid. Sellest hoolimata heitvee mõju veekogude vee kvaliteedile on märkimisväärne.

Seire tulemuste ja suublasse juhitava heitvee kogukoormuse alusel hinnati käesolevas töös reoveepuhastite puhastustaset, analüüsiti erinevate reoveepuhastite mõju ulatust veekogudele ning hinnati vajadust töötada välja rangemad reoveepuhastuse nõuded Eestis. Lisaks uuriti käesoleva töö käigus, missugustel reostusnäitajatel on kõige suurem negatiivne mõju veekogudele ning missuguseid samme peaks Eesti astuma, et olemasolevat olukorda parandada.

Tulemusena leiti, et reoveepuhasteid, mille koormus on suurem kui 2000 inimekvivalenti (ie), tuleks kontrollida järjepidevamalt, et tagada nende puhastite vastavus nõuetele, kuna nendest puhastitest pärineb ca 80% kogu reostuskoormusest, mis reoveepuhastitest üldse keskkonda juhitakse. Alla 2000 ie reoveepuhastitest keskkonda juhitav reostuskoormus on küll marginaalne, kuid on oluline analüüsida ka nendest puhastitest pärinevat kumulatiivset reostuskoormuse mõju keskkonnale. Arvestades fakti, et paljud reoveepuhastid ei vasta siiski kehtestatud nõuetele (kasutades vastavushindamiseks iga üksiku analüüsitulemuse väärtust vastavalt asulareovee puhastamise direktiivi metoodikale mitte aastakeskmiseid analüüsitulemusi), analüüs viitab asjaolule, et paljude puhastite korral analüüsitulemuste mittevastavus on tingitud üksiku reostusnäitaja väga väikesest ületamisest ja samas puhastid, mis vastavad kehtestatud nõuetele, juhivad heitveega keskkonda märkimisväärselt vähem reostust kui on kehtestatud nõuete kohaselt lubatud. Seega keskkonda juhitav puhastitest pärinev kogu reostuskoormus on tunduvalt väiksem loaga lubatavast reostuskoormusest kõikide reostusnäitajate osas.

Käesoleva doktoritöö analüüsitulemused näitavad, et heitvee kõige suurem negatiivne mõju suublatele on üldfosfori osas. Analüüsist selgub, et peale heitvee juhtimist suublasse veekogu seisund halveneb üldfosfori sisalduse osas keskmiselt ca 52%.

Töö raames hinnati ka puhastitest pärineva reostuskoormuse vähendamise võimalusi arvestades kapitali maksumust ning kaasnevat sotsiaal-majanduslikku mõju. Reoveepuhastite puhastusefektiivsust, erineva suurusega puhastite reostuskoormust, rangemate reoveepuhastusnõuete vajalikkust ja kaasnevat sotsiaal-majanduslikku mõju hinnati, arvestades seejuures nende meetmetega kaasnevat keskkonnakaitselist tulu. Töö käigus töötati välja uued heitvee piirväärtused väikestele reoveepuhastitele (alla 2000 ie).

Töö raames tehti ka mitmeid ettepanekuid riigiasutustele parandamaks veemajandusega seotud regulatsioone; nt heitvee piirnormid, heitvee ning suublaks oleva veekogu seirenõuded, andmete kogumise ja analüüsimise metoodikad eesmärgiga saada usaldusväärsemat informatsiooni vee kvaliteedi tegelikust olukorrast ning võimaldada võtta kasutusele vajalikud meetmed õigel ajal ja õiges kohas.

APPENDIX I ORIGINAL PUBLICATIONS

PAPER I

Niine, R.; Loigu, E.; Pachel, K. (2013). Compliance of wastewater treatment plants in Järva County with the EU urban wastewater treatment directive and Estonian national requirements. European Scientific Journal, 3, 365–375.

COMPLIANCE OF WASTEWATER TREATMENT PLANTS IN JÄRVA COUNTY WITH THE EU URBAN WASTEWATER TREATMENT DIRECTIVE AND ESTONIAN NATIONAL REQUIREMENTS

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Abstract:

The aim of this study was to assess the treatment efficiency conformity of Wastewater Treatment Plants to the Estonian and European Union requirements in the area of Estonian nitrate vulnerable zone as well as evaluate the existing national wastewater monitoring programme and the efficiency of the self-monitoring programme. Monitoring the results and total pollution load of effluent discharged to the receiving water body from 2007 to 2008 are used to assess the treatment level of WWTPs and the need to establish higher treatment requirements. Estonian national standards, due to the fact that Estonian water bodies are small and vulnerable to pollution, are stricter than the Urban Wastewater Treatment Directive (UWWTD) requirements. If the requirements given in UWWTD are not sufficient to achieve a good status for water bodies, it is proven that wastewater discharge adversely affects the receiving water body and this discharge is one of the important point-pollution sources for water bodies, additional stricter wastewater treatment requirements are needed. WWTPs with a more than a 2,000 population equivalent (p.e.) should be regulated vigorously to guarantee their compliance with the requirements, because WWTPs with more than 2,000 p.e. count for 80% of the total pollution load. A pollution load from WWTPs of less than 2,000 p.e. on the receiving water bodies is marginal; however, the extent of the impact of each individual WWTP depends on, among other things, the characteristics of the wastewater, the turbulence of the receiving water body and the area's sensitivity as well as other pressure sources.

Key Words: Wastewater treatment, pollution load, effluent, receiving water body

Introduction

In Estonia, Järvamaa is one of the three counties that is designated a nitrate vulnerable zone according to European Nitrates Directive (European Community (EC), 1991/1). According to Regulation no. 17 of the Estonian Government, 2003, there is one nitrate vulnerable zone consisting of two subareas – Pandivere and Adavere-Põltsamaa. In Estonia, the rivers of almost all catchment areas (excl. the islands) spring from the slopes of the Pandivere Upland karst area (Environmental Report 7, 1993). In a nitrate vulnerable zone, all water bodies are highly affected by the non-point sources from agriculture and are also easily influenced by point sources from wastewater treatment plants (WWTPs) (Valdmaa et al., 2008). It is important to control the nutrient load, particularly phosphorus pollution, even that of small settlements within agricultural and rural catchments (Jarvie et al., 2006; Iital et al., 2010). Therefore, WWTPs have to comply with the discharge requirements established by both the Urban Wastewater Treatment Directive (UWWTD) and the Estonian national standards (ENS). The European Union integrated water policy main document, which establishes a framework for EU actions in the field of water policy – Water Framework Directive (WFD), sets a goal to protect all waters against pollution and to achieve good status for all waters, promoting sustainable water and wastewater management (European Community (EC), 2000; Ministry of Environment, 2011). One of the most important surface water pressures is point-source pollution (IMPRESS, 2002). Furthermore, the Baltic Sea countries adopted an action plan to achieve the good ecological status of the Baltic Sea by 2021 (Helcom, 2007). One of the main issues covered by the Baltic Sea Action Plan is the further reduction of nutrient inputs in order to limit the eutrophication of water bodies. Estonian water bodies are sensitive to nutrients and have a high eutrophication risk. To limit the eutrophication process, it is important to decrease total phosphorous (TP) and total nitrogen (TN) loads. Several studies have researched the impact of WWTPs on receiving water bodies (Kontas et al., 2004; Millier et al., 2011; Dickenson et al., 2011). For instance, Kontas et al. (2004) studied the concentrations of inorganic nutrients, phytoplankton chlorophyll-α, and N/P ratios before and after the treatment plant. Dickenson et al. (2011) has reported on the presence of trace organic chemicals in municipal wastewater effluents. This paper uses a set of common trace organic chemicals as indicators to assess the degree of impact and attenuation of trace organic chemicals in receiving streams. Also, other Baltic countries are considering the problem of phosphorus and nitrogen removal from wastewater and, therefore, several studies have investigated the different methods of removing nutrients from wastewater. One such study, Vaboliené et al. (2007), evaluated the effect of biological nitrogen removal from wastewater on biological phosphorus removal, and Dauknys et al. (2009) analysed the influence of substrate on the biological removal of phosphorus. These studies use the results of only a few WWTPs and these analyses do not assess the cumulative impact of effluent from all regional WWTPs on receiving water bodies. This study attempts to check the compliance to the established WWTPs requirements for different sized WWTPs in Järva County and assesses the cumulative impact on receiving water bodies. Drawing from study results and taking into account the pollution load and impact on receiving water bodies, it is possible to assess the compatibility of the validated wastewater requirements in Estonia. The monitoring data of WWTPs in Järva County were compared with the requirements set by both UWWTD and ENS. ENS is based on the regulation of the Estonian Government (Government of Estonia, 2001) and water permit requirements (Ministry of the Environment, 2009/2). A further task was to estimate and compare existing national wastewater monitoring and the self-monitoring results and efficiency of WWTPs as well as make proposals to improve monitoring programmes and recommendations to change legislation. These programmes should help to evaluate the wastewater impact on the recipient and the operating efficiency of WWTPs.

Methodology for Compliance Check

The monitoring results were based on control sampling conducted by environmental authorities from 2007 to 2008. The total pollution load is calculated using monitoring results and the National Environmental Register (Ministry of the Environment, 2009/1) to get real flow rate of WWTP effluent. 154 samples from Järvamaa WWTP effluents were taken and analysed for biochemical oxygen demand (BOD_7), suspended solids (SS), TN, TP and chemical oxygen demand (COD) concentrations by the Environmental Research Centre of Estonia. The UWWTD only set limit values for WWTPs with a pollution load more than 2,000 p.e. because it aims to establish minimum treatment requirements (European Community (EC), 1991/2). The effluent limit values for WWTPs with a pollution load less than 2,000 p.e. were not regulated by these requirements. Separate criteria are used to assess the compliance of these WWTPs with the requirements. The common limit values given in the permits for the special use of water (Ministry of the Environment, 2009/2) for establishing the criteria for WWTPs with a pollution load less than 2,000 p.e. were used. Both UWWTD requirements and ENS are listed in Table 1 and 2, respectively.

Table 1. Criteria for the assessment of compliance with the UWWTD requirements

Pollution indicator	Limit values, mg/l			
	<2,000 p.e.*	2,000-9,999 p.e.	10,000-99,999 p.e.	≥100,000 p.e.
BOD_7	25	25	25	25
COD	125	125	125	125
SS	35	35	35	35
TP	-	-	2	1
TN	-	-	15	10

* The Urban Wastewater Treatment Directive does not establish common criteria and only requires an appropriate treatment level. These criteria are developed by taking into account the aim of the directives and requirements given in the permits for the special use of water.

Table 2. Criteria for the assessment of compliance with the ENS

Pollution indicator	Limit values, mg/l				
	<500 p.e.*	500-1,999 p.e.*	2,000-9,999 p.e.	10,000-99,999 p.e.	≥100,000 p.e.
BOD_7	25	25	15	15	15
COD	125	125	125	125	125
SS	25	25	25	15	15
TP	-	2	1.5	1	1
TN	-	-	-	15	10

* Estonia do not establish common standards. These criteria are developed by taking into account the aim of the directives and requirements given in the permits for the special use of water.

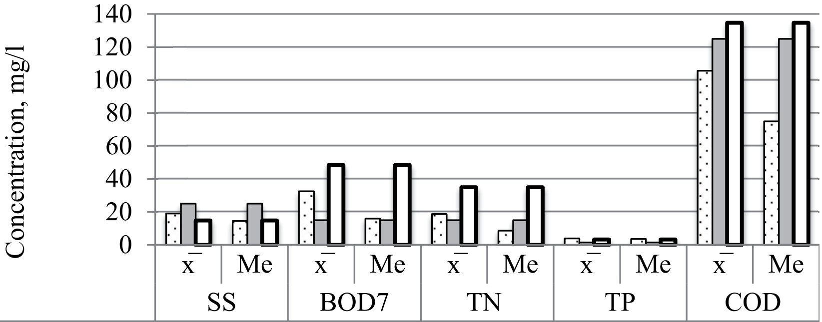
When comparing Table 2 with Table 1, two major differences can be found: 1) ENS regulates BOD_7, COD and SS for WWTPs with a pollution load from 0 p.e. to 500 p.e. and, additionally, TP from 500 to 1,999 p.e. 2) For WWTPs with a pollution load greater than 2,000, the ENS for BOD_7, SS, and TP, are 40%, 57%, and 100% higher than the UWWTD requirements, respectively.

The compliance check of WWTPs to the UWWTD requirements is only made for those WWTPs that fall within the scope of the directive. Because the UWWTD does not establish uniform requirements to be achieved for agglomerations with a pollution load of less than 2,000 p.e, requiring only an appropriate treatment level, the limit values for this study are set to achieve the good status of water bodies required by the WFD. The requirements for WWTPs with a pollution load less than 2,000 p.e. must be proportionate to the requirements for WWTPs with a pollution load more than 2,000 p.e.. Also, the requirements must comply with environmental protection objectives. The limit values for WWTPs with a pollution load less than 2,000 p.e. are given for BOD_7, COD and SS. A TN and TP removal requirement is given only for the WWTPs with a pollution load of more than 10,000 p.e. that discharge the effluent to the pollution sensitive water body according to the UWWTD. Since the whole territory of Estonia is designated as a pollution sensitive area, the criteria also demand TP and TN removal for WWTPs with a pollution load more than 10,000 p.e., as set by the UWWTD in Table 1.

To comply with the requirements, a minimum number of effluent samples are required each year, depending on the size of the WWTP. The compliance check for WWTPs with more than 2,000 p.e. is based on the principle that 3 monitoring results of 4 samples must be in conformity with the criteria set down in Table 1 or Table 2. During this study, national monitoring consists of 4 samples per year for all WWTPs with more than 2,000 p.e. and at least 2 samples per year for WWTPs with a pollution load of 500 – 2,000 p.e. All the samples on the basis of this analysis have been analysed in accredited laboratories and all water samplers have the certification of water sampling. The WWTPs of less than 2,000 p.e. are in conformity with the requirements, if all quality indicators (the criteria set down in Table 1 or Table 2) are met in more than 50% of all monitoring results. If the number of samples that confirm and the number of samples that does not confirm with the criteria set out in Table 1 or Table 2 is equal, the compliance check is based on the average monitoring results made by the water user.

Monitoring Results

Based on the 2008 monitoring results, the average effluent concentrations in mean ($\overline{x}$) and median (Me) of WWTPs in Järva County are shown in Figure 1. The mean concentration is influenced by a single extreme value of some WWTPs. The median characterises the average values of pollution indicators more adequately because the median value represents the centre of the data distribution.



	$\overline{x}$ SS	Me SS	$\overline{x}$ BOD7	Me BOD7	$\overline{x}$ TN	Me TN	$\overline{x}$ TP	Me TP	$\overline{x}$ COD	Me COD
Concentration, mg/l	19,0	14,5	32,6	16,0	18,8	8,7	4,0	3,6	105,6	75,0
Limit value, mg/l	25	25	15	15	15	15	1,5	1,5	125	125
Standard deviation (σ)	14,9	14,9	48,4	48,4	35,0	35,0	3,3	3,3	134,7	134,7

Figure 1. Average concentrations of effluent of urban WWTPs in Järva County in 2008.

Figure 1 reflects all of the 46 urban WWTPs, apart from Väätsa landfill. The limit values vary according to the size of the WWTP. The effluent average results are affected by the results of these WWTPs, which are excluded from the UWWTD. The average results of the WWTPs that are not within the scope of the directive are worse by 20% when compared to the WWTPs results given in Figure 1. If Figure 1 did not also reflect the results of the urban WWTPs, which do not belong within the scope of the UWWTD, the maximum difference would be the median of organic matter. The median of organic matter for urban WWTPs covered by the directive is 14 mg/l, which is 12.5% lower than shown in Figure 1. The median for other indicators would be lower for urban WWTPs covered by the directive between 3.5-6.7 %, compared to that given in Figure 1. There were 21 urban WWTPs that do not belong to the directive, which constitutes 42 % of all WWTPs covered in this study. Separately analysed monitoring results for the urban WWTPs that belong within the scope of the directive and the WWTPs outside the scope of the directive are given in Table 3.

Table 3. Average concentrations of the effluent of WWTPs in Järva County

	SS, mg/l		BOD_7, mgO_2/l		TN, mgN/l		TP, mgP/l		COD, mgO_2/l	
	$\overline{x}$	Me	$\overline{x}$	Me	$\overline{x}$	Me	$\overline{x}$	Me	$\overline{x}$	Me
Urban WWTPs belong to the scope of the UWWTD	17.7	14.0	24.7	14.0	15.3	8.4	3.7	3.4	85.1	70.0
Urban WWTPs outside the scope of the UWWTD	22.6	18.0	54.7	22.0	28.7	9.9	4.8	4.2	163.3	80.0
Results difference (%)	21.5	22.2	54.8	36.4	46.7	15.2	23.3	19.0	47.9	12.5

Figure 1 shows that effluent concentration is in compliance with the UWWTD requirements, except TP results, because the UWWTD does not provide TN and TP removal requirement for WWTPs with a pollution load less than 10,000 p.e. Figure 1 and Table 3 represent only two (Paide and Järva-Jaani) WWTPs effluent results with a pollution load more than 10,000 p.e., because the remaining 44 treatment plants have pollution loads less than 10,000 p.e. According to the mean of the results, some WWTPs have problems in removing organic matter. Since the average concentration of organic matter is relatively small (16 mg/l), the removal of organic matter causes difficulties for a few WWTPs in Järva County. Comparing the average concentrations of the effluent of WWTPs that belong within the scope of the UWWTD and are added to the WWTPs results that do not serve the agglomeration, the average of the results differs up to 55%.

WWTPs Compliance Check to UWWTD and ENS Requirements

WWTPs compliance check is based on the monitoring results. In 2007, 53 samples were taken from 29 different WWTPs to check compliance with the UWWTD requirements. The compliance check results show that 11 urban WWTPs (37.9 % from all plants) were in conformity with the UWWTD requirements. Only 4 plants (Türi, Paide, Koeru and Järva-Jaani) of these 29 treatment plants were with pollution loads more than 2,000 p.e. One of the WWTPs (Koeru) with a pollution load more than 2,000 p.e was in conformity with the UWWTD requirements. The compliance check to ENS was based on the 71 sampling results, which were taken from the 45 different treatment plants. Some of these plants are not within the scope of UWWTD. 12 WWTPs (26.7%) were in compliance with the ENS requirements.

In 2008, 59 samples were taken from 28 different WWTPs to assess the compliance of Järva County WWTPs with the UWWTD requirements. 18 treatment plants (already 64.3%) were in compliance. Of the WWTPs with pollution loads more than 2,000 p.e., only Paide WWTP met the requirements. The compliance check to ENS was based on the 83 samples that were taken from 47 different WWTPs. 23 WWTPs (48.9%) were in compliance with the requirements.

Taking into account that many WWTPs in Järva County are not in compliance with the established requirements, the results of concentrations of TP, TN, and BOD_7 were also evaluated. Figures 2-4 show the concentrations variability, as well as 10- and 90-percentiles of the concentrations of BOD_7, TP, and TN.

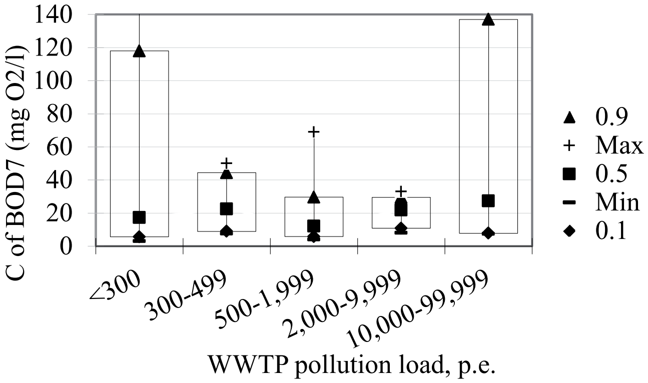


Figure 2. WWTP effluent variability of BOD_7, together with 10- and 90-percentiles in 2008

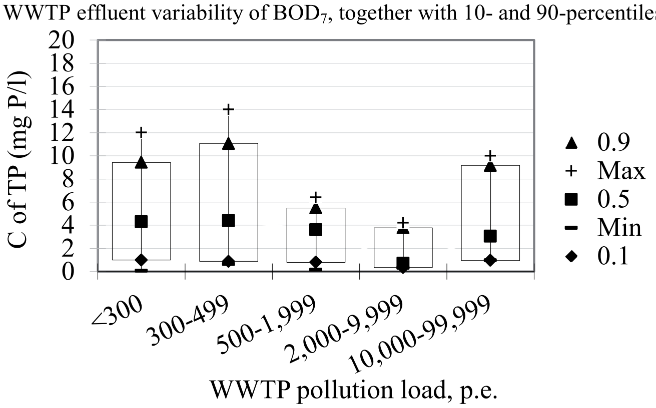


Figure 3. WWTP effluent variability of TP, together with 10- and 90-percentiles in 2008

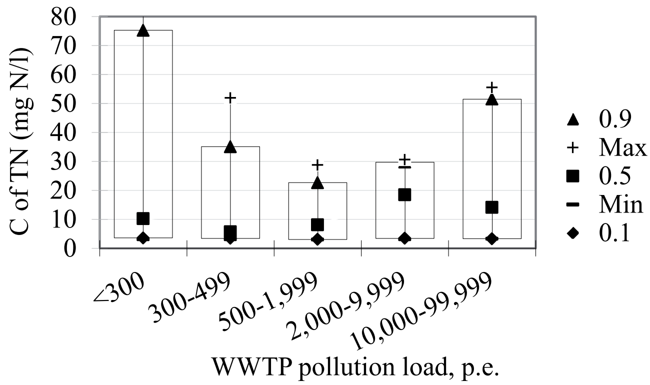


Figure 4. WWTP effluent variability of TN, together with 10- and 90-percentiles in 2008

As Figures 2-4 show, very high concentration variability exists in all WWTPs categories. We can conclude that even bigger WWTPs (more than 2,000 p.e.) have problems with the removal efficiency of all pollutants.

The results are based on the monitoring results made by Estonian Research Centre in accredited laboratories. The monitoring results obtained by WWTPs operators – the self-monitoring required according to the permits for the special use of water (Ministry of the Environment, 2009/2) – were not used in pollution load calculations, as Figure 5 indicates a significant difference in the self-monitoring and national monitoring results. The average monitoring results in 2008 made by WWTPs operators are even better; 65.2% of WWTPs are in compliance with the ENS requirements and 79.3% of WWTPs are in compliance with the UWWTD requirements using WWTPs operators self-monitoring results. Since annual average results instead of individual sample results were used, the difference between the methodologies of assessment of the compliance of WWTPs with the requirements is shown in Figure 5.

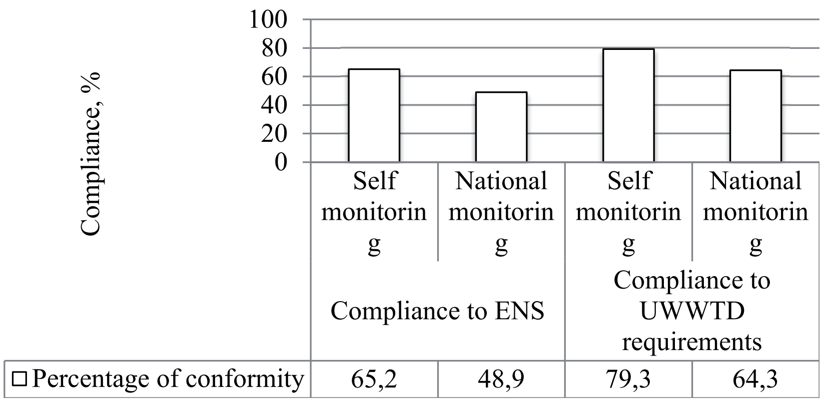


Figure 5. Percentage of compliance of WWTPs according to different methodologies, 2008

Problematic wastewater pollution indicators that do not conform to the established limit values

According to ENS, the marked part of pollution load must not discharge to the environment as shown in Figure 6. If all the WWTPs meet the requirements, the quantity of organic matter impact on water bodies would be reduce by at least 5.4 tons per year and TP 1.9 tons per year. The origin of the above normative pollution load is presented in Figure 6. An above normative pollution load discharged by WWTPs is shown with a pollution load more than 2,000 p.e. and less than 2,000 p.e., respectively.

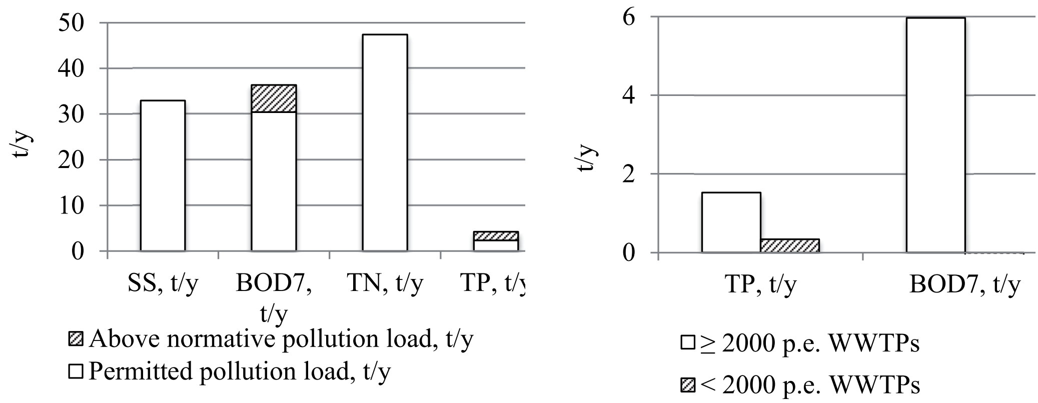


Figure 6. Total pollution load discharged to the receiving water bodies (left) and the origin of the above normative pollution load (right) in Järva County, 2008.

Figure 6 shows WWTPs with a pollution load of 2,000 p.e or more overloading the receiving water bodies with an above normative TP pollution load over 4 times more than WWTPs with a pollution load less than 2,000 p.e. It should also be pointed out that only 4 WWTPs have a pollution load more than 2,000 p.e. in Järva County and 42 WWTPs (without Väätsa landfill) have a pollution load less than 2,000 p.e.

The excessive input of organic matter distribution between WWTPs with a pollution load more than 2,000 p.e. and less than 2,000 p.e. is worse than for an excessive TP load. An above normative organic matter pollution load comes entirely from WWTPs with a pollution load more than 2,000 p.e. The actual total quantity of organic matter from WWTPs with less than 2,000 p.e. is 0.59 tons lower per year than the amount permitted by the established standards. The discharge from WWTPs with a pollution load more than 2,000 p.e. has to be reduced to protect the sensitive water bodies in Estonia. There is a need to introduce third level high-grade treatment in WWTPs, which will improve treatment efficiency and result in an immediate impact (Pachel, 2010; Bryhn, 2009; Humborg et. al, 2007).

Distribution and origin of WWTPs effluent pollution load discharged to the receiving water body

The distribution of pollution load is presented in terms of BOD_7, TP, and TN, which affect the receiving water body. Figure 7 shows that biodegradable organic matter derives 82% from WWTPs with a pollution load more than 2,000 p.e and only 18% of the total pollution load comes from less than 2,000 p.e. WWTPs. TP and TN derive 76% from the WWTPs with a pollution load more than 2,000 p.e.

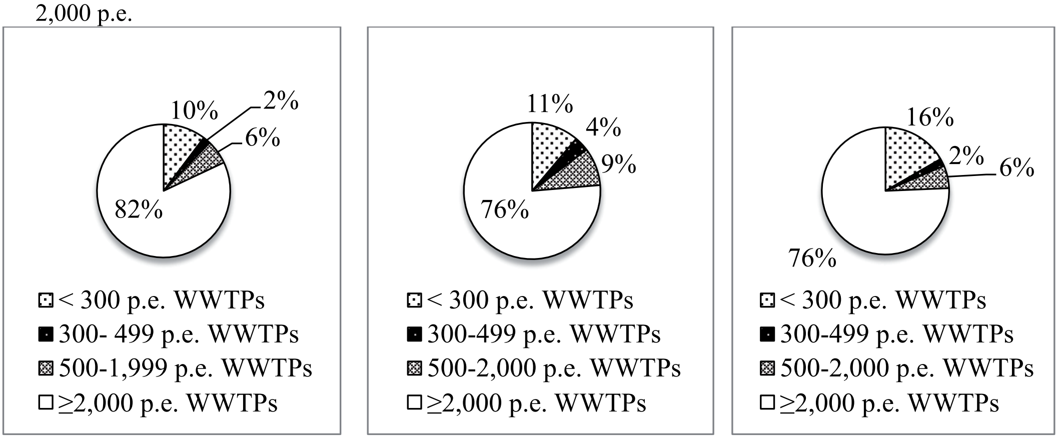


Figure 7. Distribution of BOD_7 (left), TP (centre) and TN pollution load in Järva County in 2008

Figure 7 suggests that to reduce the pollution load, which is discharged to the receiving water bodies, the discharge from WWTPs with more than 2,000 p.e. has to be reduced because WWTPs with a pollution load less than 2,000 p.e. contribute only ca 20% of the total biodegradable load discharged into the water bodies.

Discussion

The study analyses the impact of different sized WWTPs on the environment. Also, the study is unique as it was first time the cumulative impact of different sized WWTPs on the environment was analysed, using state-controlled monitoring results as well as self-monitoring results for comparison. The study reflects all 46 urban WWTPs results in Järva County and the results show that 42 WWTPs form only 18% of the entire BOD_7 pollution load and only 4 WWTPs with a pollution load of 2,000 p.e. or more form 82% of the entire BOD_7 pollution load. Similarly TP and TN pollution load distribution between WWTPs with a pollution load of less than 2,000 p.e. and more than 2,000 p.e. was 24% and 76%, respectively. The major sections of the WWTPs were constructed between the 1970s and the 1990s and have been in operation without any significant renovation; therefore, they are depreciated and outdated. Nutrient removal in these WWTPs is problematic. Eutrophication was not recognised as an important issue some decades ago. The main problem is relatively high phosphorus concentration in WWTP effluents. The high content of phosphorus causes problems in the recipient waterbodies, resulting in algae blooms and excessive plant growth. Figure 8 indicates phosphorus cumulative distribution; each point on the figure characterises a single WWTPs average result in 2007 based on 1-4 monitoring samples.

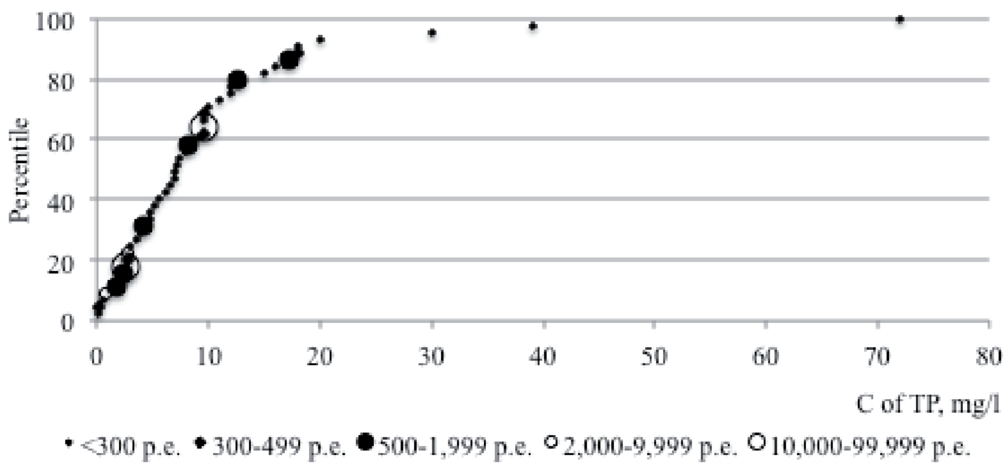


Figure 8. Percentile values of TP of different sized WWTPs in 2007

The 50-percentile value of TP for all types of WWTPs is 7.1 mgP/l; the outlet concentrations of only 5 WWTPs are below 2.0 mgP/l. To improve the ecological status of small rivers, it is necessary to improve TP values for WWTP effluents. Furthermore, existing national monitoring programmes, the data collection system, and data analyses need improvement in order to adequately assess treatment efficiency and the impact on the status of water bodies, especially in minimal runoff periods when water flow is low.

Järva County rivers have a small catchment area and, therefore, are relatively poor in water. This situation causes problems in using rivers as recipients for wastewater discharge because of insufficient dilution. Several studies point out that the majority of P tends to be retained within river systems during low-flow periods i.e. at times of greatest eutrophication risk (Jarvie et al., 2006, Pachel, 2010, Millier and Hooda, 2011, Reddy et al, 1999, Jarvie et al., 2006/2, Bukaveckas et al., 2005, Nemery and Garnier, 2007). According to the national wastewater monitoring programme, the measurements of water discharge in WWTP outlets and mixed river profile are not included at all. This is essential for calculating the actual wastewater load and its impact in low-flow rate periods. Therefore, legislation ought to be improved so that the monitoring frequency could depend on the size of the WWTP, together with the condition of the WWTP and the status of the receiving water body.

Also during this study, the above normative pollution load to obtain comprehensive information regarding the status of WWTPs was analysed. This was done to get basic knowledge on whether the established wastewater treatment standards are in conformity with the required investments and usage cost of WWTPs while taking into account that the impact of WWTPs on the environment must be minimal. As the study results show, it is essential to bring into focus WWTPs with a pollution load of 2,000 p.e. and more, while these plants have the biggest impact on the environment. On the other hand, these WWTPs are not in conformity with the established wastewater treatment standards, which cause water bodies to be overloaded with TP and biodegradable organic matter pollution. Unfortunately, it is not possible to compare the study results with earlier results due to a lack of these kinds of studies. Furthermore, as the state-controlled WWTPs effluent monitoring results show, the monitoring results differ between national and self-monitoring results by as much as 25%; therefore, it is not suitable to mix these data. As a result, self-monitoring results do not reflect the actual WWTP situation due to the low reliability of the monitoring results. During this study, we found that it is crucial to change the WWTP effluent monitoring requirements and data collecting system. Otherwise, we do not have enough reliable information about the effluent impact of WWTPs on the environment.

Also, the study shows that it is not necessary to have strict treatment standards at present, as too many WWTPs are not in compliance with today's established standards and, therefore, cause water bodies to be overloaded with TP and biodegradable organic matter pollution as a result. In Järva County, bigger WWTPs are also unexpectedly not in compliance with the established standards.

There are now several activities being implemented to reduce the significant input of organic pollutants and nutrients into water courses in Estonia. In recent years, important efforts to reduce the phosphorus load have been put into the upgrading of existing WWTPs as well as the construction of new high-grade plants with phosphorus removal and also the renewal of existing sewers and the construction of new ones in order to connect more settlements to public WWTPs. Considering the fact that most of the Estonian WWTPs are in a renovation phase at the moment, it would be necessary to analyse the WWTP effluent contaminants and nutrient ratio following the renovation of these WWTPs.

Conclusions

In Estonia, much effort has been devoted to reducing the anthropogenic loads of TN and TP to water bodies, in terms of upgrading the existing WWTPs and building new high-grade plants with nitrogen and phosphorus removal. Nevertheless, the effluent impact of WWTPs on the water bodies is considerable. The UWWTD does not impose any specific effluent limit values for WWTPs with a pollution load less than 2,000 p.e., and therefore the criteria for a compliance check have been developed in this study. However, when assessing the compliance of WWTPs with the ENS, it must acknowledge that the national requirements are much stricter than the WWTPs can actually accomplish. Only half of the WWTPs are able to comply with the national requirements. Due to the total pollutant load and origin of above normative pollution load, it is imperative to address the priority of WWTPs with a pollution load of more than 2,000 p.e., since these plants represent more than 80% of the total WWTPs pollution load and these treatment plants also have the biggest impact on the above normative pollution load because of the non-conformity treatment level.

The study indicates that due to non-compliance, WWTPs will cause rivers to overload with nutrients. The reasons for non-compliance have been due to a lack of purification capacity and operational and maintenance problems. The effluent inlets of WWTPs have the biggest adverse effect in terms of TP content in receiving water bodies. Also, the study shows that to minimise the adverse effects of effluent from WWTPs, it is not necessary to establish stricter treatment requirements, because it was apparent that the treatment levels of many WWTPs were not in compliance with the validated requirements. At the same time, it is essential to make crucial changes in legislation to improve the national monitoring programmes and data collection system. As the study results show, the self-monitoring system of the operators and the national monitoring results are not reliable enough to assess the actual state of affairs of WWTPs and the WWTP effluent impact on the receiving water bodies. On the other hand, national monitoring frequency and scope are not representative enough to make comprehensive conclusions. Therefore, we suggest changing the existing monitoring system so that all monitoring goes under state-control as well as establishing more frequent national monitoring.

This will abolish the existing double-system, improve data reliability and give more adequate information about the status of water bodies.

In summary, the study shows that:

1) the biggest impact on water bodies are WWTPs that have a pollution load more than 2000 p.e.;

2) WWTPs less than 2000 p.e. have the highest impact in terms of TP and WWTPs with a pollution load of 2000 p.e. and more having the highest impact in terms of BOD_7 and TP. Therefore, WWTPs TP removal efficiency and established TP limit values need urgent re-evaluation;

3) WWTPs self-monitoring results differ from the national monitoring results; therefore, the monitoring system needs essential changes.

Furthermore, the authors found that it is essential to undertake more complex studies in Estonia in order to analyse the cumulative impact on environmental processes.

In summary, WWTPs with more than 2,000 p.e. should be regulated vigorously to guarantee their compliance with the requirements, because WWTPs with more than 2,000 p.e. count for 80% of the total pollution load in Järva County. The number of WWTPs with less than a 2,000 p.e. impact on the receiving water bodies is marginal. Measures also have to be adopted for WWTPs with less than 2,000 p.e. to comply with the ENS, since the extent of the impact of each individual WWTP depends on, among other things, the characteristics of the wastewater and water turbulence. Also, since a very small WWTP may affect the status of a water body depending on the characteristics of the wastewater and receiving water body, particularly careful handling should be applied to the up-streams of watercourses. Considering the fact that most of the Estonian WWTPs are in a renovation phase at the moment, it would be necessary to analyse the WWTPs effluent contaminants and nutrient ratio following the renovation of these WWTPs and also re-evaluate their conformity in 2014–2015. After that, it will be possible to analyse contiguous data that were discovered during this study conducted before the WWTPs renovation phase with data collected from 2014–2015 after the renovation of the WWTPs.

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PAPER II

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Development of Estonian nutrient discharge standards for wastewater treatment plants

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Abstract. In order to comply with the Urban Wastewater Treatment Directive's, Water Framework Directive's, Helsinki Commission and Estonian National Wastewater Treatment requirements to reveal the wastewater pressures and impacts on the receiving water, the aim of this work was to develop optimal Estonian Nutrient Discharge Standards for wastewater treatment plants. Wastewater treatment plants treatment efficiency, total pollution load coming from different size of treatment plants and feasibility for stricter treatment requirements and accompanying socio-economic impacts are evaluated with consideration of environmental benefits, brought by the investment. Limit values for small-scale (below 2000 population equivalent) treatment plants were proposed.

Key words: wastewater treatment, pollution load, water quality, effluent, receiving water body, water service.

1. INTRODUCTION

The nature of water problems requires the integration of technical, economic, environmental, social and legal aspects into a coherent framework [1]. As noted in [2], operations (control) in the life cycle of a project must logically follow from planning, design and construction. It is important to keep in mind the well-known fact that the watershed, the receiving water body, urban wastewater treatment and sewer network should be considered as parts of an integrated whole. It is important to create balance between social, economic, technical and environmental aspects [3] and to take into account different alternatives, which help to find an optimal solution and to answer the key question how to identify the best technical solution among several feasible alternatives (different ecological criteria and correlation between ecology and costs must be estimated to meet the Water Framework Directive) [4–6]. Estonian regulations impose stricter wastewater treatment requirements than those set by the European Council 21 May 1991 directive 91/271/EEC for urban wastewater treatment (UWWTD). The UWWTD is based on the European Union integrated water policy main document, Water Framework Directive 2000/60/EC (WFD), which establishes a framework for Community action in water policy to protect inland surface waters, transitional waters, coastal waters and groundwater and to achieve good status of these waters. It also promotes sustainable water use [7]. The UWWTD's main goal is to protect the environment from the adverse effects of urban wastewater discharges and discharges from certain industrial sectors [8]. If the UWWTD requirements are not enough to achieve good status of water bodies and discharge is one of the important point-pollution source for water body, additional wastewater treatment will be required [9,10]. Therefore, wastewater treatment plants (WWTPs) treatment efficiency, total pollution load, coming from treatment plants of different size, and feasibility for stricter treatment requirements and accompanying socio-economic impacts are evaluated with consideration of environmental benefits, brought by the investment. In this study, all the WWTPs in the nitrate vulnerable zone are assessed in terms of biochemical oxygen demand (BOD_7), chemical oxygen demand (COD), suspended solids (SS), total phosphorus (TP) and total nitrogen (TN) discharge requirements. Estonian water bodies are very vulnerable to eutrophication due to small catchments area's and low flow rate. The stream system is relatively dense; the network of rivers longer than 10 km is 0.23 km/km^2. Most rivers are short and there are only 10 rivers longer than 100 km and only 13 rivers have their mean annual average flow over 10 m^3. The total runoff of Estonian rivers in an average year is 11.7 km^3, being only 5.5 km^3 in very dry (95% probability) years. Upper parts of Estonian rivers are particularly poor in water and in low water periods the flow can be almost zero [11,12]. This situation causes problems in using rivers as recipients for wastewater discharge because flow of dry periods does not dilute wastewater sufficiently, thus highly efficient wastewater treatment is required [1].

Eutrophication is caused by excessive nutrients such as phosphorus and nitrogen in water body from either natural or anthropogenic sources. Agricultural chemicals, industrial, and municipal wastewater consists of organic components, phosphorus and nitrogen, contribute to eutrophication process. The other Baltic countries are also considering the problem of phosphorus and nitrogen removal and, therefore, several studies have investigated different methods of removing nutrients from wastewater [13–16]. To limit eutrophication, the HELCOM Baltic Sea Action Plan set stricter urban wastewater treatment requirements [17–19]. However, socio-economic impacts due to more stringent requirements must be examined to achieve satisfactory water quality. In addition, the Estonian regulation requires that all investments must ensure full cost recovery and must be recovered through water tariffs. The optimal wastewater treatment requirement must be determined to achieve good status of the water body with wastewater treatment cost in conformity with environmental benefits. The treatment efficiency of different WWTPs will be determined so that the required investments will result in the maximum efficiency in the reduction of the effluent pollution load. Optimal limit values for small-scale (below 2000 p.e.[1]) [20] WWTPs are also discussed during this study by using common treatment technologies.

2. ASSESSMENT OF THE POLLUTION LOAD OF WWTPs

In Estonia, WWTPs' effluent quality requirements are regulated in the Regulation of the Government No. 269, 31 July 2001 under "Requirements for discharge of wastewater into surface water and soil". Effluent requirements established in the regulation referred to above are much more stringent than those set in the UWWTD [21]. Although the fundamental principles of the directive have been adopted into the Estonian regulation, additional requirements are implemented due to the vulnerability of Estonian water bodies. Estonian rivers have commonly a low flow rate and, due to human activity, a high eutrophication potential. Breaking the eutrophication, one of the most important tasks of water authorities [22] is still the major environmental problem [23–29]. UWWTD of the EU merely sets the minimum requirements for wastewater discharge; wastewater limit values are developed based upon specific country's situation. If stricter requirements are necessary to achieve the objective of other directives, member states have to implement more stringent requirements according to economic reality and socio-economic impact. In addition, financial costs to upgrade WWTPs shall be proportionate to the environmental benefits. To ensure sustainable infrastructure, the necessary expenses incurred in the operation of the system have to be covered with the water tariffs according to Estonian legislation. To make water service accessible to the general public, the public sewage system areas (agglomerations) are determined so that public water service price shall not apply more than 4% of the annual average net income of households in that area in Estonia. This threshold is often quoted in the range of 3%–5% of household income in OECD countries [30]. Estonian, European Union and Helsinki Commission regulations of effluent limit values are shown in Table 1.

Table 1 shows that only for a WWTP with pollution load greater than 2000 p.e. [31], a common standard to assess the compliance of WWTPs with requirements is established. National compliance of WWTPs were assessed by the monitoring results of Järvamaa WWTPs during 2008; 83 wastewater samples were taken from 47 different WWTPs; 23 WWTPs or 49% were in compliance with the treatment requirements.

[1] Population equivalent (p.e.) is a conventional unit of mean daily water pollution, caused by one person. The value of one population equivalent expressed by biochemical oxygen demand (BOD_7) is 60 g of oxygen per day.

Table 1. Estonian National (EE), European Union (EU) and Helsinki Commission (HE) wastewater discharge criteria

Legislation	BOD_7, mgO_2/l	COD, mgO_2/l	SS, mg/l	TP, mgP/l	TN, mgN/l
≥100 000 p.e.					
EE	15	125	15	1	10
EU	25	125	35	1	10
HE	15	–	–	0.5	10
10 000–99 999 p.e.					
EE	15	125	15	1	15
EU	25	125	35	2	15
HE	15	–	–	0.5	15
2 000–9 999 p.e.					
EE	15	125	25	1.5	–
EU	25	125	35	–	–
HE	15	–	–	1	30%
500–1 999 p.e.[2]					
EE	25	125	25	2	–
EU	25	125	35	–	–
HE*	25	–	–	2	35
<500 p.e.[2]					
EE	25	125	25	–	–
EU	25	125	35	–	–
HE**	*Alternative 1*: the requirements based on emissions per capita need not apply where it can be shown that an on-site WWTP results in at most a concentration of BOD_5 of 20 mg/l, P_{tot} 5 mg/l and TN_t 25 mg/l in the effluent of the WWTP. *Alternative 2*: the requirements based on emissions per capita need not apply where it can be shown that an on-site WWTP using the Best Available Technology (BAT) is installed and operated so that the treatment results in a concentration of BOD_5 of at most 40 mg/l and 150 mg/l COD in the effluent of the WWTP.				

* 300–2000 p.e.
** Less than 300 p.e.

To set the realistic standards, the loads from WWTP effluents to receiving water bodies, was estimated. WWTPs effluents' samples results were analysed in different water bodies. The most agricultural intensive area such as Järva county is used. The Nitrates Directive [32] also specified this county as a nitrate vulnerable zone. All water bodies in Järva county have the highest eutrophication potential in Estonia due to intensive agricultural activities. The impact of the

[2] EE and EU do not establish common standards. These standards are developed taking into account the aim of directives and requirements given in the permits of water special use.

pollution load, coming from point source pollution of Järva county on water bodies, is analysed.

The actual pollution loads were calculated in 2008 on the basis of the real flow rate of wastewater and monitoring results of wastewater influent and effluent. Permissible pollution loads have been calculated in 2008 on the basis of real flow rate of wastewater and established Estonian national limit values for pollution indicators (Table 1) [21,33]. The flow rates of wastewater used were obtained from the national database kept by the Estonian Environment Information Centre. WWTPs with the pollution load of 2000 to 10 000 p.e., the average influent concentration for TN was approximately 60 mgN/l. For WWTPs of 150 to 2 000 p.e., the influent concentration was 86 mgN/l and for WWTPs less than 150 p.e. approximately 106 mgN/l [34]. For WWTPs less than 10 000 p.e., the national threshold of TN have not been set (Table 1). Since 30% of the TN removal is achievable if the biological treatment process functions normally and operates properly without enhanced nitrogen removal (such as nitrification-denitrification process) [35] and considering HELCOM recommendation (Table 1), the effluent concentrations for TN are calculated as 30% reduction of concentration of WWTPs' inflow (Table 2).

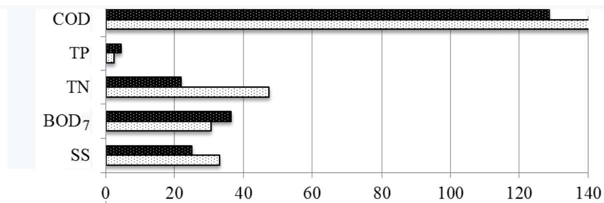
The effluent TP limit value for WWTPs with the pollution load 500–2000 p.e. set in special water permits of 2 mgP/l (Table 1), was also decided to use for WWTPs with load between 300 and 500 p.e. for calculation of permissible pollution load. For WWTPs of smaller load, less than 300 p.e., weaker socio-economical situation was considered in our study, thus lower limit value of 3 mgP/l was the basis for the TP permissible load calculations.

Compared to the UWWTD requirements, the levels would be even higher than the permissible pollution load illustrated in Fig. 1, because the directive requirements are less rigorous than the Estonian national requirements.

Permissible pollution loads have been calculated in 2008 on the basis of the real flow rate of wastewater and established Estonian national limit values for pollution indicators (Tables 1 and 2) [21,33]. The actual pollution loads were calculated on the basis of the real flow rate of wastewater and the monitoring results of the effluent. The difference between the actual and permissible pollution load shows how much it is possible to reduce the total pollution load in conditions where all WWTPs are in compliance with the established requirements.

Table 2. Average TN concentrations of WWTPs influent and TN limit values for WWTPs effluent using 30% reduction

Pollution load of the WWTP, p.e.	Average C of TN in influent of the WWTP, mg/l	Removal proportion, %	TN limit values in effluent of the WWTP, mg/l
2000–9999	60	30	42
150–1999	86	30	60
<150	106	30	74



	SS	BOD_7	TN	TP	COD
■ Actual pollution load	24.98	36.38	21.79	4.27	128.64
□ Permissible pollution load	32.92	30.42	47.38	2.36	231.17

Fig. 1. Point source pollution load in Järva county in 2008, t/y.

As Fig. 1 shows, the actual pollution load discharged to the receiving water bodies is smaller than the load which is in accordance with the national requirements of COD, TN and SS. Figure 1 also suggests that WWTP should be upgraded to remove TP. TP pollution load discharged to the receiving water bodies is higher than what is allowed according to the permissible point source pollution load. Among the non-compliant plants, most of them have the problems in removing phosphorus and organic matter. Compared to the pattern in Fig. 1 with the average concentrations of pollutants, many non-compliant plants have problems with phosphorus removal but just some of plants have problems with removal of organic matter. High concentration or high flow rate (e.g. Roosna-Alliku, Järva-Jaani) has a major impact on total pollutant loads.

The HELCOM Baltic Sea Action Plan enables for removal of TN to use either 30% of reduction or limit values in concentrations, which is for less than 10 000 p.e. WWTPs 35 mg/l, respective total permissible load of TN is 38 t/y. Figure 1 shows that using reduction percentage, the quantity of TN is 47 t/y, which is 24% more pollution than using the concentration 35 mg/l for all WWTP less than 10 000 p.e.

3. SOCIO-ECONOMIC IMPACT OF NITROGEN DISCHARGE STANDARDS

To achieve goals set by the HELCOM recommendations [[18]], treatment requirements for less than 10 000 p.e. WWTPs by selecting either 30% of reduction of the TN or limit concentration of effluent to 35 mgN/l. Costs for nitrogen removal to achieve 35 mgN/l were estimated and are summarized in Table 3. In Tables 3 and 6, for investment calculations results of the project report [[34]] are used.

Table 3. The additional expenditure for implementing TN concentration of 35 mg/l bargain for existent technologies

Size of WWTP, p.e.	Exploitation cost for TN removal, EUR/y	Investment cost for TN removal, EUR	Total additional cost for nitrogen removal, EUR/y
≥100 000	0	0	0
10 000–99 999	0	0	0
2 000–9 999	3 800–12 800	128 000	2000–8600
500–1 999	960–3 800	43 500	2000–7000
300–499	700–960	222 000	4500–7000
150–299	320–700	146 000	2300–4500
50–149	130–320	74 800	1100–2300
10–49	30–130	34 500	260–1100
<10	30	8 700	260

Table 2 shows that to achieve TN concentration of 35 mg/l, 42% of total nitrogen reduction rate for WWTP with the pollution load of 2000 to 10 000 p.e., 59% for 150 to 2000 p.e. and 67% for less than 150 p.e. WWTPs is needed. However, such treatment efficiency can only be achieved by using tertiary treatment such as nitrification and denitrification processes. To ensure the functioning of nitrification-denitrification processes for 2000 to 9999 p.e. WWTPs, further investments in technological devices and pipes, 36 500 EUR is required; 91 500 EUR is required for tank expansion. Therefore the total capital is 128 000 EUR per WWTP.

According to EU rules, the amount of investments should result in proportional environmental benefits. Therefore, total investment and environmental benefits in terms of pollution load reduction for different sizes of WWTPs are plotted in Fig. 2.

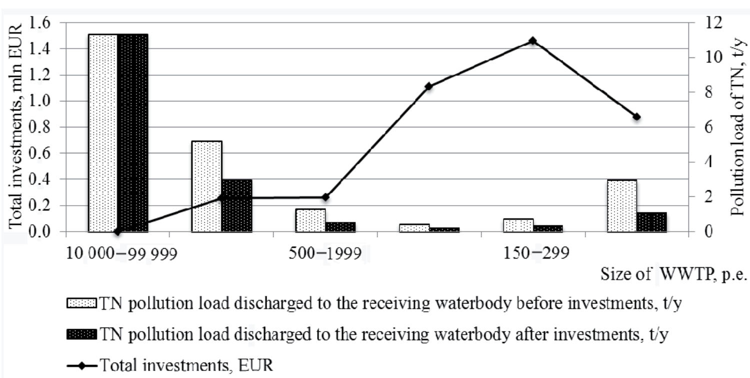


Fig. 2. Pollution load of TN before and after introducing stricter limit values and additional investments.

Figure 2 suggests that WWTPs, discharging less pollution load to the receiving water bodies, need higher investments to achieve TN limit concentration of 35 mg/l. WWTPs with the pollution load less than 10 000 p.e. have significantly higher TN load of the influent than WWTPs with pollution load more than 10 000 p.e. Therefore, at least 40% of reduction of TN is required for WWTPs with the pollution load of 2000 to 10 000 p.e., and for 300 to 2000 p.e., about 60% of reduction of TN and less than 300 p.e. up to 67% of reduction. However, for WWTPs with the pollution load less than 500 p.e., TN reduction, and the amount of investments are not comparable. The WWTPs less than 500 p.e. discharge to the receiving water body about 4 t TN per year, of which 1.6 t come from Väätsa landfill. At the same time, 3.3 millions of EUR investment will reduce the discharge only 2.5 t per year, which is half of the nitrogen removal for 7000 p.e. WWTP discharge quantity of TN per year, if there is no existent nitrogen removal process. It should be noted that the reduction is calculated as maximum reduction, on condition that there is no existent nitrogen removal process today at all. The actual reduction of the TN pollution load may be up to 30% less than is indicated in Fig. 2, because the existing biological treatment processes can remove up to 30% of TN. In Fig. 2, two bigger than 10 000 p.e. plants (Järva-Jaani and Paide) discharge to the receiving water body 11.3 t TN/y, and smaller than 10 000 p. e. plants (a total of 45 plants) form all together 10.5 t/y. Implementation of the C_{TN} of 35 mg/l means higher water service price for population. Table 4 gives an overview of the necessary additional expenses by implementing TN limit value of 35 mg/l and its impact on the price of water service to the population.

Table 4 describes the exploitation costs entailed implementation of TN concentration of 35 mg/l. Based on Fig. 2 and Table 4, implementation of C_{TN} of 35 mg/l for WWTPs with the pollution load less than 500 p.e. would be

Table 4. The socio-economic impact of implementing TN limit concentration of 35 mg/l

Pollution load of WWTP, p.e.	No. of WWTP	Actual TN pollution load of effluent, t/y	C_{TN} in influent, mg/l	C_{TN} in effluent, mg/l	Reduction rate of TN, %	Additional exploitation cost per WWTP for TN removal, EUR/y	Additional cost in water price, EUR/m^3	TN pollution load of effluent after investments, t/y
≥100 000	0	0	61	10	84	0	0	0
10 000–99 999	2	11.30	61	15	75	0	0	11.30
2 000–9 999	2	5.18	61	35	43	5300	0.021	2.95
500–1 999	6	1.25	86	35	59	4500	0.025	0.51
300–499	5	0.42	86	35	59	5800	0.35	0.17
150–299	10	0.72	86	35	59	3500	0.38	0.29
<150	22	2.92*	106	35	67	1300	0.54	1.05

* Pollution load contains also the load of Väätsa landfill, which is 1.6 t of TN per year.

infeasible from the economical and environmental aspects. Implementation of C_{TN} of 35 mg/l for WWTPs with the pollution load less than 500 p.e., the water service price will rise from 0.35 to 0.54 EUR/m^3. At the same time, a smaller quantity of TN reaching the water body has a marginal importance comparing it to the TN total pollution load reaching the water body. Great investment difference for plants of different size is due to the fact that in WWTPs with the pollution load more than 500 p.e., the TN removal will be achievable improving the existing technologies, but for WWTPs less than 500 p.e. the TN level 35 mg/l will be possible to achieve only by constructing a new WWTP.

In summary, the authors have an opinion that the implementation of C_{TN} 35 mg/l for WWTPs with the pollution load less than 10 000 p.e. is justified only if the concentration 35 mg/l is used for WWTPs with the pollution load between 500 and 9999 p.e., and WWTPs between 300 and 499 p.e. are used either with the reduction rate of 30% or C_{TN} of 60 mg/l, which can be achieved as a result of properly operated biological treatment processes without enhanced nitrogen removal.

4. SOCIO-ECONOMIC IMPACT OF PHOSPHORUS DISCHARGE STANDARDS

The HELCOM Baltic Sea Action Plan pays special attention to nutrient removal and the recommendations set the limit values for both, TN and TP concentration, to restrict the eutrophication of the Baltic Sea [17–19]. The socio-economic impact for using stricter requirements of TP is discussed below. The impact assessment is based on limit values of TP, proposed by the HELCOM as listed in Table 5.

Table 6 gives an overview of the expenditures to achieve the TP requirements for different sizes of WWTPs.

All the additional expenditures are calculated as maximum expenditures, which means that the cost for implementing stricter TP requirements are calculated by assuming that all WWTPs with pollution load less than 2000 p.e. do not have phosphorus removal. For WWTPs with the pollution load less than 2000 p.e., where the phosphorus requirement is applied already today, additional expenditures given in Table 6 with the stricter phosphorus requirements do not

Table 5. Phosphorus discharge standards according to HELCOM recommendations

Pollution load of WWTP, p.e.	TP, mgP/l
≥100 000	0.5
10 000–99 999	0.5
2 000–9 999	1
300–1 999	2
<300	2

Table 6. The additional expenditure for implementing stricter requirements for TP for existent technologies

Size of WWTP, p.e.	Exploitation cost for TP removal, EUR/y	Investment cost for TP removal, EUR	Total additional cost for TP removal, EUR/y
≥100 000	1500–6800	9000	5800–9600
10 000–99 999	150–1 500	6100	1900–5800
2 000–9 999	50–150	450	1900–2500
500–1 999	960–4000	3200	1300–2500
150–499	260–960	2400	1100–1300
<150	20–260	450	160–1100

apply. Additionally, WWTPs with the pollution load more than 2000 p.e., the calculation is based on the simplification that today these plants use only chemical phosphorus removal. In case a WWTP has both chemical and biological phosphorus removal today, the considerable additional expenditures are not necessary with new stricter phosphorus requirements and water service price will increase only from 0.03 to 0.04 EUR/m^3.

For WWTPs with pollution load more than 2000 p.e., the impact is calculated so that the TP limit concentration will decrease by 0.5 mgP/l. Table 7 and Fig. 3 show that the C_{TP} is justified if pollution load of WWTP is higher than 300 p.e. For smaller plants, the additional costs for stricter phosphorus removal forms in water service price from 0.27 to 0.43 EUR/m^3, while reduction of TP discharged to the receiving water body has no considerable influence. For WWTP with less than 300 p.e., no dramatic reduction of phosphorus pollution load will result. For the WWTPs with the pollution load between 300 and 10 000 p.e., the price of water service will increase from 0.04 to 0.11 EUR/m^3. The additional investments need implementing stricter TP requirements and the resulting environmental benefits are presented in Fig. 3.

Table 7. Socio-economic impact of implementing stricter phosphorus discharge standards

Pollution load of WWTP, p.e.	No. of WWTP	Actual TP load of effluent, t/y	Influent C_{TP}, mgP/l	Effluent C_{TP}, mgP/l	Additional cost per WWTP for TP removal, EUR/y	Additional cost in water price, EUR/m^3	TP load of effluent after investments, t/y
≥100 000	0	0	13.8	0.5	7 700	0.0	0.00
10 000–99 999	2	2.76	13.8	0.5	3 900	0.006	1.38
2 000–9 999	2	0.48	13.8	1	2 200	0.04	0.32
500–1 999	6	0.38	19.6	2	1 900	0.10	0.25
300–499	5	0.15	19.6	2	770	0.11	0.07
150–299	10	0.18	19.6	2	450	0.27	0.09
<150	22	0.31	22.5	2	130	0.43	0.16

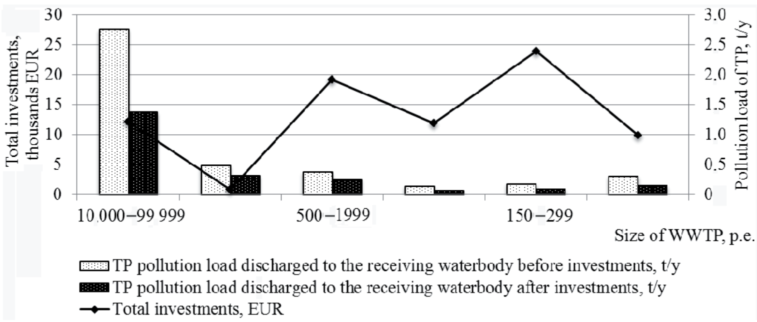


Fig. 3. Pollution load of TP before and after introducing stricter limit values and additional investments.

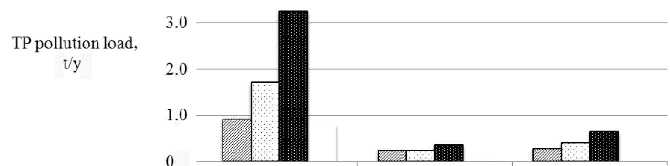
Figure 3 shows that the stricter phosphorus requirements do not lead to the very high investment needs. Investment need is estimated by assuming that WWTPs with pollution load less than 2000 p.e. have no chemical and biological phosphorus removal. When WWTP has chemical phosphorus removal today then the additional investments may not be necessary. Several studies show that phosphorus reduction is achievable even without any specific phosphorus removal strategy if the optimum dose of chemicals is used [[36,37]]. WWTPs with the pollution load 2000 p.e. or more must apply phosphorus removal according to the existing treatment requirements. Therefore, assessment of investments takes into account that these plants apply the chemical treatment of phosphorus. If these plants apply both chemical and biological phosphorus removal today, the investment needs will be up to 90% less.

5. RECOMMENDATION FOR EFFLUENT STANDARDS OF WWTPs IN ESTONIA

Actual pollution load of WWTP effluent discharged to the recipient and the existing treatment requirements according to the EU requirements are analysed to set the TN and TP standards. Different sizes of WWTP pollution load, discharged to the recipient, were evaluated and additional investments need and environmental benefit were analysed to achieve the EU TN and TP requirements. Different sizes of WWTPs effluent pollution loads, discharged to the recipient, were assessed to determine the cumulative impact on the environment. Figures 4–6 present discharged TP, TN and BOD_7 pollution loads to the receiving water bodies.

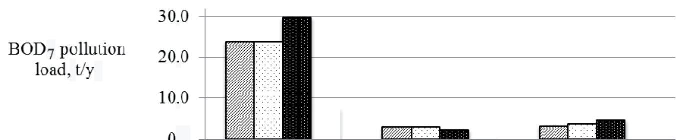
Figure 4 shows the indicative TP limit concentrations, which are the basis for calculating total pollution load of phosphorus. The actual pollution load is found from the monitoring results and real wastewater flow rates in 2008. Permissible pollution load is calculated on the basis of real flow rate of wastewater and established Estonian national limit values for pollution indicators (Tables 1 and 2). WWTP over 2000 p.e. in Fig. 4 is the permissible limit of C_{TP} 1 to 1.5 mgP/l. For WWTP more than 10 000 p.e., the permissible limit concentration is 1 mgP/l and for WWTP between 2000 to 10 000 p.e. the limit concentrations is 1.5 mgP/l (Table 1, EE wastewater discharge criteria). Greater than 10 000 p.e WWTPs are Paide (35 010 p.e.) and Järva-Jaani (12 000 p.e.). WWTPs between 2000–10 000 p.e. are Türi (7632 p.e.) and Koeru (2035 p.e.). Similarly is calculated pollution load using the HE requirement (Table 1, HE wastewater discharge criteria) and on the basis of real flow rate of wastewater.

Figure 6 shows that actual TN loads, discharged to the receiving water bodies, are considerably smaller than it is permitted by the existing requirements.



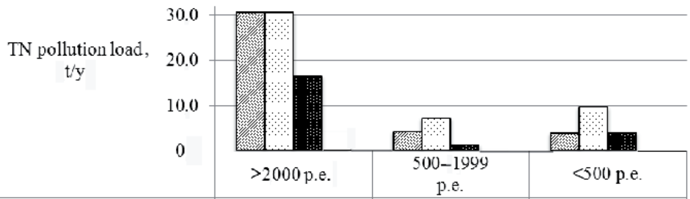
	≥2000 p.e.	500–1999 p.e.	<500 p.e.
Pollution load using HE requirement, t/y	0.92	0.24	0.29
Permissible pollution load, t/y	1.71	0.24	0.41
Actual pollution load, t/y	3.24	0.36	0.65
Average pollution load per WWTP, t/y	0.81	0.06	0.01

Fig. 4. Actual and permissible TP pollution loads, and effluent TP load using HE requirements for different size WWTPs in Järva county in 2008.



	≥2000 p.e.	500–1999 p.e.	<500 p.e.
Pollution load using HE requirement, t/y	23.80	3.00	3.04
Permissible pollution load, t/y	23.80	3.00	3.62
Actual pollution load, t/y	29.77	2.13	4.47
Average pollution load per WWTP, t/y	7.44	0.36	0.12

Fig. 5. Actual and permissible BOD_7 pollution load and effluent BOD_7 load using HE requirements for different size WWTP's in Järva county in 2008.



	>2000 p.e.	500–1999 p.e.	<500 p.e.
Pollution load using HE requirement, t/y	30.55	4.19	3.91
Permissible pollution load, t/y	30.55	7.19	9.64
Actual pollution load, t/y	16.48	1.25	4.06
Average pollution load per WWTP, t/y	4.12	0.21	0.11

Fig. 6. Actual and permissible TN pollution load and effluent TN load using HE requirements for different size WWTP's in Järva county in 2008.
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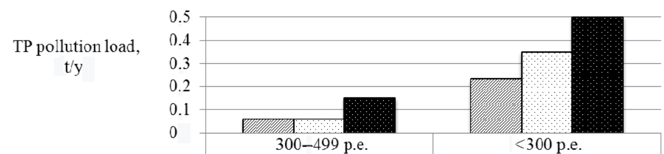
Comparing Fig. 6 to Figs 4 and 5, the balance of nutrients in sewage is not optimal, because the TP and organic matter is partially not removed due to the deficiency of nitrogen in sewage. Therefore, sewage treatment processes need to be improved to ensure the optimal nutrients and organic matter ratio for bacteria. Figs 4–6 imply that the largest pollution load is caused by WWTPs with the pollution load more than 2000 p.e. (in Järva county, 4 WWTPs). There are six WWTPs with the pollution load between 500 and 2000 p.e. and in the group less than 500 p.e. there are 37 WWTPs. Figures 4–6 suggest that to limit the amount of pollution load, all WWTPs with the pollution load more than 2000 p.e. must be reduced. For over 2000 p.e. plants, one WWTP causes about 0.81 t TP pollution load per year. Nationally water permit limits the concentration of TP generally for WWTPs more than 500 p.e. [33,38]. The phosphorus removal will also be required in the future for WWTPs between 300 and 500 p.e. [18]. For WWTPs below 500 p.e., TP load distribution is presented in Fig. 7.

For WWTPs less than 500 p.e., effluent pollution load is comparable with the WWTPs of the size between 500 and 2000 p.e. The TP actual pollution load per



	300–499 p.e.	<300 p.e.
Pollution load using HE requirement, t/y	0.06	0.23
Permissible pollution load, t/y	0.06	0.35
Actual pollution load, t/y	0.15	0.50

Fig. 7. TP load distribution between different size of WWTPs below 500 p.e.

Table 8. New wastewater discharge standards; limit concentration, mg/l

Pollution indicator	WWTP size, p.e.					
	<300	300–499	500–1999	2 000–9 999	10 000–99 000	≥100 000
BOD_7	25	25	25	15	15	15
COD	125	125	125	125	125	125
SS	25	25	25	25	15	15
TP	N/A	2	2	1	0.5	0.5
TN	N/A	60	35	35	15	10

one WWTP for WWTPs less than 500 p.e. is 0.01 t/y, considering the number of these plants, the total pollution load is 0.65 t/y. To compare the effluent pollutant load of WWTPs less than 2000 p.e. with those of more than 2000 p.e., the load from smaller than 2000 p.e. plants is very small. However, taking into account the amount of TP, given in Figs 4 and 7, and socioeconomic impact by implementing stricter requirements for phosphorus removal and also recipients sensitivity of phosphorus, it is expedient to impose the TP limit concentration of 2 mg/l for WWTPs between 300 and 2000 p.e. Also the distribution of the TP load between different sizes of WWTPs is taken into account, according to which more than 2000 p.e. WWTPs effluent load is 80% of TP load and less than 2000 p.e. effluent form only 20% of the total pollution load. Accordingly, the TP reduction requirement is reasonable for WWTPs with the pollution load more than 300 p.e., but by assessing the amount of phosphorus pollution load the limit concentration for TP should not be stricter than 2 mg/l for WWTPs between 300 and 2000 p.e. Based upon the above analysis, new wastewater discharge standards, developed during this study, are given in Table 8.

6. CONCLUSIONS

In Estonia, no national limit values for the effluent of WWTPs with pollution load less than 2000 p.e. are fixed. In this study, pollution load reduction is assessed according to its capital requirements and socio-economic impacts. The main conclusions of this study are the following.

1. Wastewater criteria of nutrients, found during this study, are needed. The national standards for WWTPs with the pollution load less than 2000 p.e. have to be established.
2. Given the origin of pollution and the level of investment required, WWTPs bigger than 2000 p.e. have to be improved to achieve existing standards. The pollution load bigger than 2000 p.e. WWTPs discharge to the receiving water bodies about 80% of the total pollution load.
3. The WWTPs effluent TN requirement of 35 mgN/l is not appropriate for WWTPs below 500 p.e., taking into account the amount of investments and TN pollution load reduction after investments. For WWTPs with the pollution

load less than 500 p.e., the TN reduction and the amount of investments are not comparable. The WWTPs less than 500 p.e. discharge to the receiving water body about 4 t TN per year, of which 1.6 t come from Väätsa landfill; 3.5 millions of EUR investment will reduce it to only 2.5 t TN per year. Therefore we found that this requirement would be infeasible considering economical and environmental aspects. Implementation of C_{TN} of 35 mg/l for WWTPs with the pollution load less than 500 p.e., the water service cost will rise between 0.35 and 0.54 EUR/m^3 while, at the same time, a smaller quantity of TN reaching the water body has a marginal importance comparing it to the TN total pollution load reaching the water body.

4. Taking into account the socioeconomic analysis results, the stricter phosphorus requirements do not lead to very high investment needs. Total investments need is approximately 78 000 EUR in Järva county and after these investments the TP pollution load discharged to the environment will reduce about 2 t/y. Investment need was estimated during this study by assuming that WWTPs with pollution load less than 2000 p.e. have no chemical and biological phosphorus removal. If WWTP has chemical phosphorus removal already today, the additional investments may not be necessary.
5. Implementing stricter wastewater treatment requirements means higher water service cost for population. At the same time, the study shows that to limit eutrophication, the reduction of nitrogen and phosphorus content in effluent discharged into a recipient must attain. Nutrient effluent standards for WWTPs with the pollution load more than 300 p.e. are needed for environmentally and economically reasons. More stringent requirements than is reflected in this study would not be proportionate to the environment effect and does not guarantee comparable pollution load reduction to the investments for WWTPs with less than 300 p.e. Also stricter wastewater treatment requirements than is given in this study may cause the problems of accessibility of water service due to high water price.

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Ühtsete reovee puhastusnormide väljatöötamine Eesti reoveepuhastitele

Raili Niine, Enn Loigu ja Walter Z. Tang

On vaadeldud Eesti reoveepuhastite heitvee mõju ulatust suublale ja hinnatud reovee puhastamisele esitatud nõuete asjakohasust. On analüüsitud 83 proovi tulemusi, mis on võetud 47 erinevast Järvamaa reoveepuhasti heitveest. Analüüs on tehtud Järvamaa reoveepuhastite näitel, sest Järvamaa suublad on reostusainete suhtes eriti tundlikud, kuna tegemist on kõrge intensiivsusega põllumajanduspiirkonnaga. Eestis puuduvad ühtsed reovee puhastusnormid reoveepuhastitele, mille reostuskoormus on alla 2000 i.e. On välja töötatud reoveepuhastite reostuskoormuse piirnormid kõikidele reoveepuhastitele, arvestades puhastitest suublasse juhitava reostuskoormuse suurust, piirnormide rakendamisega kaasnevat sotsiaalmajanduslikku mõju ja keskkonnakaitselist aspekti. Suurimat negatiivset mõju keskkonnale avaldavad puhastid, mille reostuskoormus on suurem kui 2000 i.e., kuid reostuskoormuse vähendamine on oluline ka väiksemate kui 2000 i.e. reoveepuhastite renoveerimisel ja ühtsete reoveepuhastusnormide rakendamisel.

PAPER III

Niine, Raili; Loigu, Enn; Pachel, Karin (2013). Distribution of Different Pollution Loads from Wastewater Treatment Plants and their Impact on Water Bodies in Estonia. International Journal of Energy and Environment, 7(2), 86–95.

Distribution of different pollution loads from wastewater treatment plants and their impact on water bodies in Estonia

Raili Niine, Enn Loigu, Karin Pachel

Abstract: There are many small-sized wastewater treatment plants in Estonia; therefore, it is essential to analyse the cumulative impact of the pollution load from these kinds of wastewater treatment plants. Wastewater is one of the biggest causes of point source pollution and has a negative effect on the quality of water bodies. In Estonia, all water bodies are categorised as sensitive water bodies according to European Council directive 91/271/EEC of 21 May 1991 for urban wastewater treatment. Therefore, all Estonian wastewater treatment plants have much higher treatment standards than most other European regions. The aim of this study was to analyse the different pollution loads of wastewater treatment plants that are discharged to the environment in Estonia and assess what kind of wastewater treatment plants have the biggest impact on the receiving water bodies. Also, during this study, research was conducted into what kinds of wastewater pollutants have the greatest adverse effect on water bodies and what kind of steps Estonia needs to take to improve this.

***Key Words*:** pollution load, treatment level, wastewater pollutants, wastewater treatment plant.

I. INTRODUCTION

Estonian water bodies are quite vulnerable to eutrophication due to their small catchment areas and low flow rates. The stream system is relatively dense; the network of rivers longer than 10 km is 0.23 km/km^2. Most rivers are short and there are only 10 rivers longer than 100 km, with 13 rivers having a mean annual average flow exceeding 10 m^3. The total runoff from Estonian rivers in an average year is 11.7 cubic kilometres, but is only 5.5 cubic kilometres during very dry (95% probability) years. The upper courses of Estonian rivers are particularly scarce of water and in low water periods the flow can be almost zero [1], [2]. This situation causes problems in using rivers as recipients for wastewater discharge because of insufficient dilution [3]-[5]. Several studies refer to the fact that most of the P tends to be retained within river systems during low-flow periods i.e. at times of greatest eutrophication risk [6]-[9]. Therefore, Estonian regulations impose stricter wastewater treatment requirements than what have been set by the European Council directive 91/271/EEC of 21 May 1991 for urban wastewater treatment (UWWTD). The UWWTD's main goal is to protect the environment from the adverse effects of urban wastewater discharges and discharges from certain industrial sectors [10]. If the UWWTD requirements are not sufficient to achieve a satisfactory status for water bodies, and discharge is one of the main causes of point source pollution for water bodies, additional wastewater treatment will be required [11], [12]. Table I gives an overview of the different wastewater treatment requirements in Estonia and the European Union.

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Table I. Estonian National (EE) and European Union (EU) wastewater discharge standards

	Biochemical oxygen demand (BOD_7), mgO_2/l	Chemical oxygen demand (COD), mgO_2/l	Suspended solids (SS), mg/l	Total phosphorus (TP), mgP/l	Total nitrogen (TN), mgN/l
≥100,000 p.e.					
EE	15	125	15	1	10
EU	25	125	35	1	10
10,000-99,999 p.e.					
EE	15	125	15	1	15
EU	25	125	35	2	15
2,000-9,999 p.e.					
EE	15	125	25	1.5	-
EU	25	125	35	-	-
500-1,999 p.e.[A]					
EE	25	125	25	2	-
EU	25	125	35	-	-
<500 p.e.[A]					
EE	25	125	25	-	-
EU	25	125	35	-	-

[A]EE and the EU do not establish common standards. These standards are developed by taking into account the aim of the directives and requirements given in the permits for the special use of water.

Also, the Baltic Sea countries have adopted an action plan to achieve a satisfactory ecological status for the Baltic Sea by 2021 [13]. The eutrophication of surface waters and the sea enhanced by the anthropogenic input of nitrogen and phosphorus from point and diffuse sources is one of the main environmental concerns in the Baltic Sea Region [14]-[19], and globally [20], [21]. One of the main issues covered by the Baltic Sea Action Plan is the further reduction of nutrient inputs in order to limit the eutrophication of water bodies. In this study, it is analysed whether the stricter treatment requirements are sufficient in protecting water bodies from the adverse effect of effluent. Also, other countries are considering the problem of the treatment level of wastewater and, therefore, several studies have investigated the WWTPs impact on the environment, e.g. [22] studied the status of the treatment of municipal wastewater in Slovenia, [23] evaluated the possibility of improving nutrient removal efficiency according to the new, stricter discharge limits, [24] developed a method to optimise the calculation of modelling wastewater treatment systems and [25] assessed different types of WWTPs that can be included in the so-called small WWTPs category.

II. METHODOLOGY

During the study, a total of 774 different wastewater treatment plants (WWTPs) were analysed, from which 67 serve the agglomeration areas with a pollution load of 2,000 p.e. or more and all other WWTPs serve agglomeration areas where the pollution load is less than 2,000 p.e. It should be mentioned that Estonia has a total of 59 agglomeration areas with 2,000 p.e. or more but all the WWTPs that serve these areas must comply with 2,000 p.e. or more agglomeration area requirements. Therefore, this study covers almost all Estonian WWTPs that serve agglomerations with a pollution load of 2,000 p.e. or more, most smaller WWTPs that serve agglomeration areas with less than 2,000 p.e. and even the WWTPs that do not serve an agglomeration area at all and are built as individual WWTPs. The analysis is based on 2,249 single sample results, which were taken from different sized effluents from WWTPs to analyse BOD_7, SS, TN, TP and COD concentrations and additionally 1,198 samples results, which were taken from the appropriate upper and lower courses of receiving water bodies from the WWTP effluent inlet.

The analysis on the wastewater samples was carried out in accredited laboratories in Estonia using standardised methodology SFS 5505:1988 for TN, EVS-EN ISO 6878:2004 for TP, ISO 5815-1:2003 for BOD_7, EVS-EN 872:2005 for SS and ISO 6060:1989 for COD. Additionally, all the samples were taken by qualified samplers, who have been granted attestation and all the samples were analysed in accredited laboratories. All receiving water body samples consist of three samples – surface water sample before WWTPs effluent inlet to the receiving water body, surface water sample after WWTPs effluent inlet and WWTP effluent sample. BOD_7, SS, TN, TP and COD were also analysed in all of these samples. It must also be mentioned that the upper course water body sample was taken approximately 500 m before the effluent inlet to the water body and the lower course sample was taken where wastewater is well mixed with surface water, and the real place depended on all the water body and wastewater characteristics, such as turbulence, water flow rate, etc. Therefore, the sample was not taken from the place next to the WWTP effluent inlet to the water body.

III. DISTRIBUTION OF DIFFERENT POLLUTION LOADS FROM WWTPS

From 2007-2008, which was the sampling period, the average efficiency of the WWTPs (using BOD_7, TP, TN, SS and COD concentrations) in 2008 was 48% according to the Estonian national requirements and 65% according to the UWWTD requirements. These results show that it is important to investigate what kind of WWTPs have the highest impact on water bodies and how the pollution load that is discharged into the water bodies is divided between the different sized WWTPs.

Table II. Estonian WWTP effluent pollutants average values, in 2008

BOD_7, (mgO_2/l)	TP, (mgP/l)	TN, (mgN/l)	SS, (mg/l)	COD, (mgO_2/l)
11.9	3.4	14.9	18.3	71.9

Table II results show that the BOD_7, TP and TN impact on the water bodies is highest when taking into account that the average WWTPs effluent pollutants concentration in part of TP exceeds the average TP limit value, and average concentrations in part of TN and BOD_7 are quite close to TN and BOD_7 average limit values.

Table III gives an overview of the effluent conformity of WWTPs in concentrations of BOD_7, TP and TN.

Table III. WWTPs effluent conformity check

Size of WWTP (p.e.)	No of WWTPs	No of samples	BOD_7 conformity (%)		TP conformity (%)		TN conformity (%)	
			2007	2008	2007	2008	2007	2008
≥ 100,000	10	47	50	80	27	56	27	44
10,000-99,999	16	82	77	77	49	56	51	60
2,000-9,999	41	135	39	50	17	30	77	87
500-1,999	138	503	72	79	23	36	93	96
300-499	98	293	66	67	19	35	86	95
<300	313	815	64	67	33	44	87	89
Industries	158	374	63	61	53	52	88	88
Average conformity (%)	774	2,249	61	69	32	44	73	80

As Table III shows, TN removal is not a problem for WWTPs with pollution loads below 2,000 p.e. and also quite good conformity is evident for WWTPs with pollution loads of 2,000-10,000 p.e. If we compare Table III results with Table I, which gives an overview of the wastewater treatment requirements, we can see that TN do not have limit values for WWTPs with pollution loads less than 10,000 p.e. Nevertheless the conformity assessment is made for WWTPs with pollution loads less than 10,000 p.e. using 30% TN removal requirements, as 30% of the TN removal is achievable if the biological treatment process functions normally and operates properly. Similarly, TP conformity is carried out for WWTPs with pollution loads less than 500 p.e. using TP limit value 2 mg/l for WWTPs of 300-500 p.e. and 3 mg/l for WWTPs under 300 p.e. All other limit values are given in Table I according to the EE wastewater discharge standards that we used during conformity assessment. Table III also shows that WWTPs treatment level notably improved during the period 2007-2008. The biggest hot spot is TP conformity, which was only 44% in

2008; at the same time, BOD_7 and TN conformity was 69% and 80%, respectively.

Using the study results that reflect 774 different sized WWTPs effluent analyses, the total pollution load discharged into the environment in terms of BOD_7, TP and TN is given in Table IV.

Table IV. Total pollution load (tons per year) in 2008.

Pollutant	Pollution load (t/y)	
	≥ 2,000 p.e. WWTPs	< 2,000 p.e. WWTPs
TP	74.84	29.60
TN	981.51	194.42
BOD_7	687.07	404.92

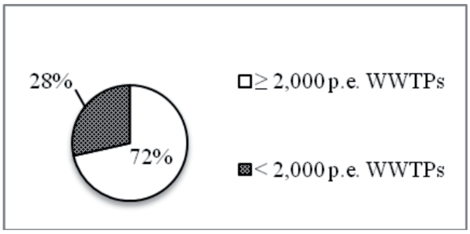

Fig.1. Origin of TP pollution load

As Fig.1 and Table IV show, WWTPs with pollution loads of 2,000 p.e. or more have the greatest impact as these plants together form 72% of the entire TP pollution load and only 28% of the TP pollution load comes from WWTPs with less than 2,000 p.e.

Origin of BOD_7 and TN pollution load is given in Fig.2 and Fig.3.

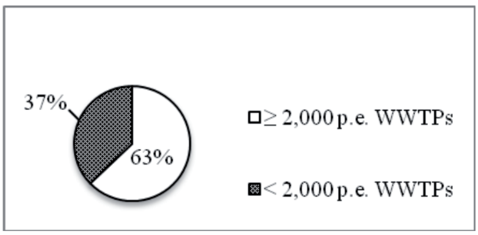

Fig.2. Origin of BOD_7 pollution load

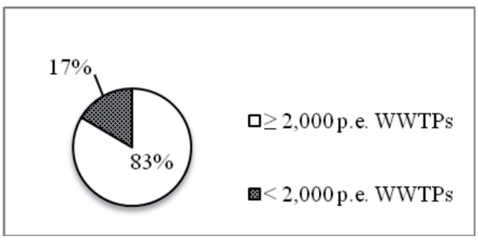

Fig.3. Origin of TN pollution load

As Fig.1, 2, and 3 show, the biggest pollution load on the environment comes from the WWTPs with pollution loads of 2,000 p.e. or more. WWTPs with less than 2,000 p.e. have the highest impact in the BOD_7 pollution load, as these plants form 38% of the entire BOD_7 pollution load discharged into the environment.

To obtain a more specific overview of the origin of the total pollution loads of different sized WWTPs, the distribution is given below. Tables V-VI give an overview of the TP pollution load. Table V reflects the TP pollution load that is discharged into the environment from the WWTPs with pollution loads of 2,000 p.e. or more and Table VI shows the TP pollution load distribution that is discharged into the environment from the WWTPs that are smaller than 2,000 p.e. and also Table VI reflects the industrial pollution. The industrial pollution load consists of different industrial sectors, WWTPs that serve farms, landfills and all other sectors that do not qualify as urban wastewater.

Table V. TP pollution load (tons per year) distribution between the WWTPs with pollution loads of 2,000 p.e. or more

Region	≥ 100,000 p.e.	10,000-99,999 p.e.	2,000-9,999 p.e.	Total	No of WWTPs
Harju	31.84	2.51	4.29	38.63	24
Hiiu	0	0	0.34	0.34	2
Ida-Viru	4.75	0.19	0.17	5.11	3
Järva	0	2.76	0.48	3.24	2
Jõgeva	0	0.63	0.97	1.61	4
Lääne-Viru	0.69	0.08	3.15	3.92	8
Lääne	0	0.20	0	0.20	1
Põlva	0	0.44	0.23	0.67	3
Pärnu	7.27	0	0.54	7.82	4
Rapla	0	0.54	1.72	2.26	4
Saare	0	1.52	0	1.52	1
Tartu	4.01	0	0.19	4.20	4
Valga	0	0.77	0.45	1.23	5
Viljandi	0	2.92	0	2.92	1
Võru	0	1.18	0	1.18	1
Total	48.56	13.73	12.55	74.84	67

Table VI. TP pollution load (tons per year) distribution between the WWTPs with pollution loads of less than 2,000 p.e.

Region	500-1,999 p.e.	300-499 p.e.	< 300 p.e.	Industries	Total	No of WWTPs
Harju	1.62	0.25	0.41	2.89	5.16	72
Hiiu	0.29	0	0.19	0.03	0.52	21
Ida-Viru	0.06	0.02	0.001	0.11	0.19	7
Järva	0.38	0.15	0.30	0.20	1.03	52
Jõgeva	1.22	0.15	0.23	0.36	1.96	46
Lääne-Viru	1.14	0.27	0.58	0.72	2.71	62
Lääne	0.27	0.17	0.27	0.96	1.66	41
Põlva	0.22	0.26	0.48	0.20	1.16	28
Pärnu	1.17	0.20	0.44	0.49	2.30	85
Rapla	0.69	0.26	0.27	1.22	2.44	28
Saare	1.04	0.30	1.16	0.44	2.94	37

Tartu	1.04	0.64	0.65	1.31	3.64	73
Valga	0.36	0.13	0.33	0.01	0.83	38
Viljandi	0.37	0.36	0.26	0.17	1.16	70
Võru	0.67	0.41	0.15	0.67	1.91	47
Total	10.55	3.55	5.73	9.77	29.6	707

Taking into account the results of Tables IV, V and VI, we can admit that, although the analyses represent 707 WWTPs, which serve the agglomeration areas with pollution loads less than 2,000 p.e. and only 67 WWTPs, which serve the agglomeration areas with pollution loads of 2,000 p.e. or more, 72% of the entire TP pollution load derives from WWTPs with pollution loads more than 2,000 p.e.

Tables VII and VIII describe the origin of BOD_7 pollution loads. Table VII shows the BOD_7 pollution load distribution between WWTPs with pollution loads of 2,000 p.e. or more and Table VIII shows the BOD_7 pollution load distribution between WWTPs with pollution loads less than 2,000 p.e. as well as the industrial sector (also consists of farms, landfills and all other sectors that are not deemed part of the urban wastewater pollution load).

Table VII. BOD_7 pollution load (tons per year) distribution between WWTPs with pollution loads of 2,000 p.e. or more

Region	≥ 100,000 p.e.	10,000-99,999 p.e.	2,000-9,999 p.e.	Total	No of WWTPs
Harju	154.05	83.19	178.06	415.31	24
Hiiu	0	0	2.05	2.05	2
Ida-Viru	71.94	2.16	0.76	74.85	3
Järva	0	24.33	5.44	29.77	2
Jõgeva	0	0.94	2.18	3.12	4
Lääne-Viru	28.73	0.44	19.66	48.83	8
Lääne	0	3.16	0	3.16	1
Põlva	0	2.23	0.31	2.53	3
Pärnu	22.37	0	2.81	25.19	4
Rapla	0	6.58	10.91	17.49	4
Saare	0	20.77	0	20.77	1
Tartu	26.28	0	0.95	27.23	4
Valga	0	2.60	2.33	4.94	5
Viljandi	0	6.20	0	6.20	1
Võru	0	5.62	0	5.62	1
Total	303.37	158.23	225.47	687.07	67

Table VIII. BOD_7 pollution load (tons per year) distribution between WWTPs with pollution loads of less than 2,000 p.e.

Region	500-1,999 p.e.	300-499 p.e.	< 300 p.e.	Industries	Total	No of WWTPs
Harju	8.40	1.95	1.98	18.09	30.42	72
Hiiu	0.45	0	1.29	0.10	1.84	21
Ida-Viru	0.17	0.22	0.04	20.40	20.82	7
Järva	2.13	0.66	1.74	2.08	6.61	52
Jõgeva	6.38	1.34	0.85	3.30	11.87	46
Lääne-Viru	7.39	1.79	2.53	182.8	194.5	62
Lääne	2.21	1.37	1.60	3.27	8.45	41
Põlva	1.77	1.72	4.75	8.20	16.44	28
Pärnu	2.80	0.49	1.68	3.65	8.62	85
Rapla	5.13	1.16	2.62	8.92	17.84	28
Saare	2.15	4.05	11.9	2.98	21.06	37
Tartu	3.82	3.83	4.29	22.78	34.72	73
Valga	2.18	0.63	1.55	0.04	4.41	38
Viljandi	3.42	2.28	2.57	4.05	12.32	70
Võru	1.80	2.37	1.02	9.86	15.05	47
Total	50.2	23.9	40.4	290.5	404.9	707

Tables VII and VIII also show that 67 WWTPs form 63% of all the BOD_7 pollution load of all 774 WWTPs. 67 WWTPs discharge 687 tons BOD_7 per year into the environment and the remaining 707 WWTPs discharge 405 tons BOD_7 pollution into the environment.

Tables IX and X show the TN pollution load distribution. Table IX reflects WWTPs with pollution loads of 2,000 p.e. or more and Table X reflects WWTPs with less than 2,000 p.e.

Table IX. TN pollution load (tons per year) distribution between the WWTPs with pollution loads of 2,000 p.e. or more

Region	≥ 100,000 p.e.	10,000-99,999 p.e.	2,000-9,999 p.e.	Total	No of WWTPs
Harju	503.17	41.15	20.69	565.01	24
Hiiu	0	0	2.35	2.35	2
Ida-Viru	96.04	4.94	1.80	102.77	3
Järva	0	11.30	5.18	16.48	2
Jõgeva	0	5.13	2.35	7.48	4
Lääne-Viru	33.00	1.23	17.78	52.01	8
Lääne	0	11.02	0	11.02	1
Põlva	0	3.20	1.38	4.58	3
Pärnu	57.95	0	2.36	60.30	4
Rapla	0	2.36	11.52	13.87	4
Saare	0	27.70	0	27.70	1
Tartu	54.88	0	1.93	56.81	4
Valga	0	8.41	2.26	10.67	5
Viljandi	0	7.47	0	7.47	1
Võru	0	43.00	0	43.00	1
Total	745.03	166.90	69.59	981.51	67

Table X. TN pollution load (tons per year) distribution between the WWTPs with pollution loads less than 2,000 p.e.

Region	500-1,999 p.e.	300-499 p.e.	< 300 p.e.	Industries	Total	No of WWTPs
Harju	7.72	1.33	1.45	35.82	46.32	72
Hiiu	1.63	0	0.79	0.08	2.50	21
Ida-Viru	0.38	0.95	0.03	1.51	2.88	7
Järva	1.25	0.42	1.63	2.01	5.31	52

Jõgeva	6.48	0.95	1.04	3.36	11.83	46
Lääne-Viru	5.40	1.67	3.16	31.84	42.06	62
Lääne	1.52	0.89	1.24	2.28	5.94	41
Põlva	1.03	1.23	2.52	2.06	6.83	28
Pärnu	5.79	0.78	1.79	1.08	9.44	85
Rapla	3.99	0.68	0.85	5.52	11.05	28
Saare	4.28	1.73	3.84	1.60	11.45	37
Tartu	4.88	3.41	3.77	7.60	19.67	73
Valga	1.61	0.59	1.47	0.02	3.70	38
Viljandi	3.46	1.74	1.49	0.85	7.55	70
Võru	2.80	1.85	0.87	2.39	7.90	47
Total	52.2	18.2	25.9	98.04	194.4	707

Tables IX and X show that the TN pollution load distribution between WWTPs with 2,000 p.e. or more and less than 2000 p.e. is the most drastic due to 83% of all TN pollution load being discharged into the environment by the WWTPs that serve the agglomeration areas with pollution loads of 2,000 p.e. or more.

Taking into account that many WWTPs in Estonia are not in compliance with the established requirements, the total actual pollution load and permissible pollution load discharged into the environment was also compared.

Fig.4 shows the actual pollution load discharged into the environment by the 774 WWTPs that are analysed during this study. Permissible pollution loads have been calculated on the basis of the real flow rate of effluent and established national limit values for pollution indicators (see Table I). The flow rates of wastewater used were obtained from the national database maintained by the Estonian Environment Information Centre. The actual pollution loads were calculated on the basis of the real flow rate of wastewater and the monitoring results of effluent. The effluent TP limit value for WWTPs with pollution loads of 500-2,000 p.e. set in special water permits of 2 mgP/l (Table I) was also used for WWTPs with pollution loads between 300 and 500 p.e. For WWTPs with smaller loads, i.e., less than 300 p.e., a weaker socio-economic situation was considered in our study; therefore, a lower limit value of 3 mgP/l was the basis for the TP permissible pollution load calculations. For WWTPs below 10,000 p.e., the permissible pollution load is calculated using 30% of TN removal, since 30% of the TN removal is achievable if the biological treatment process functions normally and operates properly without enhanced nitrogen removal (such as nitrification-denitrification process). The difference between the actual and permissible pollution load shows how much it is possible to reduce the total pollution load in conditions where all WWTPs are in compliance with the established requirements.

Fig-s. 5 and 6 show the BOD_7, TN and TP actual and permissible pollution loads discharged into the environment by 774 WWTPs.

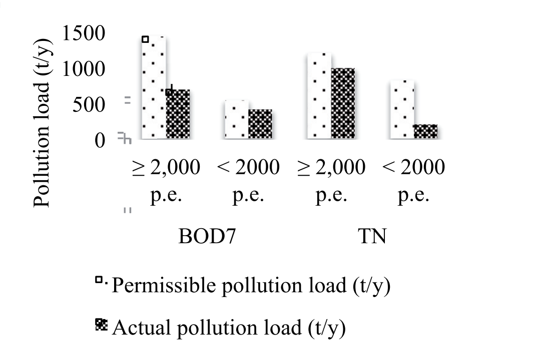

Fig.4. Actual and permissible BOD_7 and TN pollution loads discharged into the environment by 774 WWTPs.

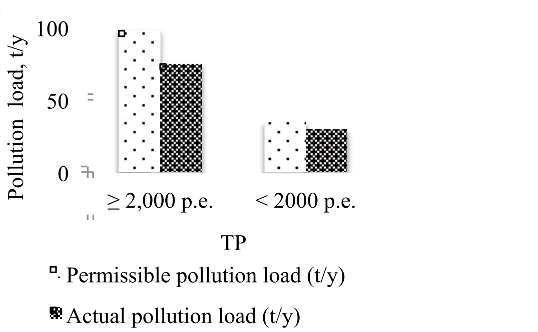

Fig.5. Actual and permissible TP pollution load discharged into the environment by 774 WWTPs.

As we consider the results from Fig. 4 and Fig. 5, the total pollution load discharged into the environment is much less than the permissible pollution load permit due to the established wastewater treatment standards. If we consider the fact that many WWTPs were not in compliance with the established requirements, the analysis concludes that many WWTPs are slightly exceeding the limit values and the WWTPs that are in compliance with the established requirements for discharges into the environment are emitting notably less pollution than the established limits.

Fig-s. 6-8 show the actual pollution load distribution between different sized WWTPs and its comparison to the permissible pollution load.

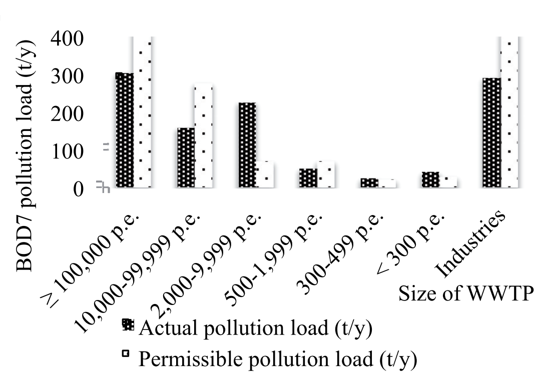

Fig.6. BOD_7 actual and permissible pollution load distribution

As Fig 6. shows the biggest adverse effect to the environment by non-permitted pollution is caused by WWTPs with pollution loads of 2,000-10,000 p.e. All other categories discharge less BOD_7 pollution into the environment than the set limits.

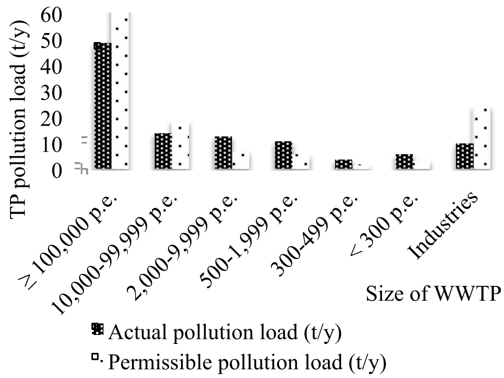

Fig.7. TP actual and permissible pollution load distribution

As Fig.7 shows that the TP removal level is not in compliance for WWTPs with pollution loads of 0-10,000 p.e. Therefore, the TP removal level in the total pollution load is only in compliance with the established requirements for WWTPs with pollution loads of 10,000 p.e. or more and for industrial sector WWTPs.

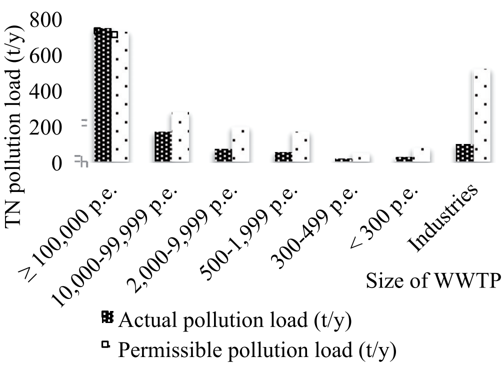

Fig.8. TN actual and permissible pollution load distribution

As Fig.8 shows that TN removal is a slight problem for WWTPs with pollution loads of 100,000 p.e. or more; all other WWTPs are in compliance with the permissible pollution load.

Taking into account the results of Figs. 6-8, during this study we calculated the overloaded pollution load of these WWTPs categories that do not comply with the permissible pollution load. In this analysis, we found that it is possible to reduce the actual pollution load in terms of TP by at least 14.8 tons per year: 5.6 tons from WWTPs with pollution loads of 2,000-10,000 p.e.; 5 tons from WWTPs with pollution loads of 500-2,000 p.e.; 1.9 tons from WWTPs with pollution loads of 300-500 p.e., and 2.3 tons from WWTPs with pollution loads less than 300 p.e. Also, it is possible to reduce actual pollution loads in terms of BOD_7 by at least 171 tons per year: 156 tons from WWTPs with pollution loads of 2,000-10,000 p.e.; 3 tons from WWTPs with 300-500 p.e., and 12 tons from WWTPs with less than 300 p.e. Additionally, it is possible to reduce actual pollution load in terms of TN by at least 22.7 tons and all the overload comes from WWTPs with pollution loads of 100,000 p.e. or more.

In conclusion, the major part of overloading comes from WWTPs with pollution loads between 2,000 and 10,000 p.e. and in terms of TN from WWTPs with pollution loads of 100,000 p.e. or more. Using actual total pollution loads and permissible pollution load calculations, it is possible to reduce the TP pollution load that is discharged into the environment by at least 14%, the BOD_7 pollution load by at least 16%, and the TN pollution load by at least 2%.

IV. WWTPS EFFLUENT IMPACT ON THE WATER BODIES

Considering the effluent pollutant concentrations of WWTPs, in this study the impact of every single WWTP effluent on certain water body quality was analysed. The average concentrations of WWTPs effluent pollutants show that it is important to analyse the wastewater impact on water bodies, while considering whether a single WWTP is in accordance with the Estonian national standards or not.

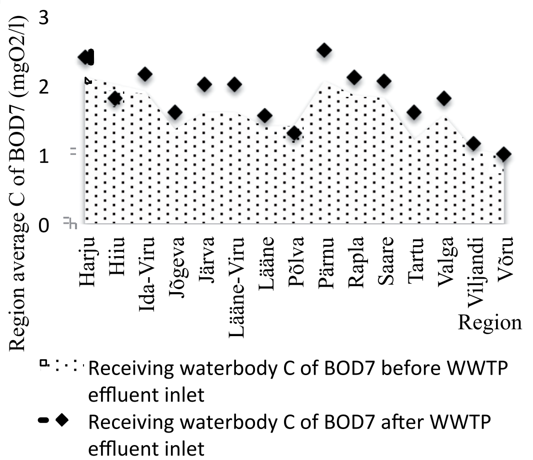

Fig. 9. WWTP effluent average BOD_7 impact on the receiving water body in Estonia

As Fig. 9 shows, in today's WWTPs conditions, the WWTPs effluent inlet impacts the receiving water body quality. The receiving water body quality has deteriorated by approximately 13% since the WWTP effluent inlet to the receiving water body.

Taking into account the results in Fig. 9 and even if we consider that the WWTP effluent adversely affects the receiving water body, the absolute values show that the main effluent impact is not significant enough to change the status of the receiving water body. The water body has a good status in terms of BOD_5, if the BOD_5 concentration varies from different watercourses from 1.8-3.5 mgO_2/l [26] and as we can see in the Fig. 9, the water bodies average BOD_7 concentrations vary after WWTP effluent discharge from 1.0-2.5 mgO_2/l, which do not exceed the limit values established by the legal document. Therefore, we may conclude that BOD_7 is not the biggest problem for the quality of Estonian water bodies. However, the biggest part of BOD_7 overload comes from WWTPs with pollution loads of 2,000-10,000 p.e. and, additionally, the small WWTPs (below 500 p.e.) are largely not in accordance with the BOD_7 removal requirements, although the total pollution load from these plants is marginal.

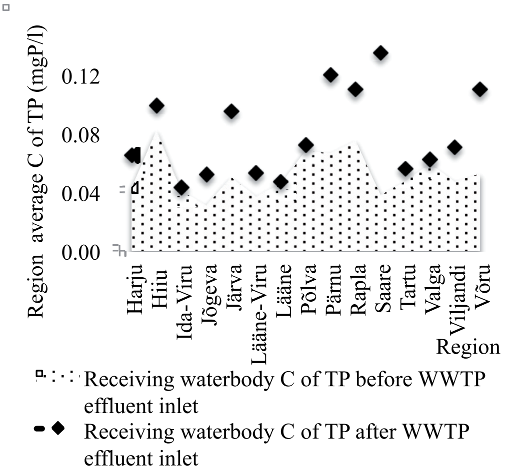

Fig. 10. WWTP effluent average TP impact on the receiving water body in Estonia

Estonian water bodies are sensitive and have a high eutrophication risk. The main element that limits primary production and in turn the eutrophy of inland water bodies is phosphorus [27]. Therefore, Fig. 10 also shows that the WWTP effluent TP concentration has much a higher impact on the water body than BOD_7 concentration. The study shows that the receiving water body quality has deteriorated by as much as 52% since the WWTP effluent inlet to the water body.

The TP values show that there is a strong impact on the status of the receiving water body. The water body has a good status in terms of TP, if TP concentration is between 0.04-0.08 mgP/l [26] and, as we can see in the Fig. 10, the average TP concentrations of water bodies vary after WWTP effluent discharges from 0.04-0.14 mgP/l. The TP concentration between >0.1-0.12 mgP/l means that the water body status is poor and below 0.12 mgP/l the water body status is bad.

As in Fig. 10, the biggest impact occurs in the Järva, Pärnu, Rapla, Saare and Võru regions.

Table XI. WWTP impact on the receiving water body in the Pärnu and Järva regions

Receiving water body	Water body C of TP before WWTP effluent inlet	Water body C of TP after WWTP effluent inlet
Pärnu region		
Uruste	0.27	0.32
Audru	0.063	0.083
Tõstamaa	0.07	0.1
Kaldoja	0.1	0.12
Vaheliku	0.29	0.95
Arumetsa	0.049	0,098
Lähkma	0.037	0.28
Reiu	0.036	0,041
Tori	0.41	0,12
Ura	0.081	0,11
Järva region		
Lokuta	0.04	1.2
Lintsi	0.05	0.1
Pärnu	0.04	0.12
Navesti	0.33	0.8
Vanavälja	0.28	0.36
Jägala	0.09	1.5
Ambla	0.02	0.03
Järva-Jaani	0.03	1.2
Peetri	0.05	0.07
Sääsküla	0.02	0.19
Pärnu jõgi	0.05	0.07

Table XI gives some examples of the WWTP effluent impact on receiving water bodies in the Järva and Pärnu regions. The biggest adverse effect is small tributaries and main ditches, such as Lokuta, Vanavälja, and Järva-Jaani, where the flow rate is very low all-year round in the Järva region. Therefore, even a small amount of discharged pollution has a significant adverse effect on the water body. At the same time, wastewater from the WWTPs discharged into Lokuta river, Navesti river, Vanavälja main ditch and Järva-Jaani ditch is not treated as required. And, as we can see in Table XI, all of these WWTPs for which the treatment level is not in line with the requirements influence the status of the water body. On the other hand, Pärnu river, which is one of the biggest rivers in Estonia and has several tributaries, does not have any adverse effect or has a minimal adverse effect from the effluent inlet to the water body, although there are also WWTPs that are not in compliance with the requirements. The mean annual average flow rate of Pärnu river is 50-65 m^3/s in the lower course [28] and this is the reason why the adverse effluent effect of WWTPs is minimal. In the Järva region, the water bodies are also quite vulnerable because of intensive farming and the flow rate is very low in most of the receiving water bodies. Therefore, even a marginal pollution load may cause problems for the water quality.

In the Pärnu region, it is possible to indicate that the biggest adverse effect is on smaller water bodies, mostly minor streams or very small rivers, where the flow rate is low, e.g. Ura. Also, WWTP treatment is not at the required level in many places, which causes an adverse effect.

Table XII. WWTP efficiency (using BOD_7, TN, TP, SS and COD concentrations in WWTP effluent) in Järva, Pärnu, Rapla, Saare and Võru regions.

Region	WWTP efficiency, %			
	Estonian national requirements		UWWTD requirements	
	2007	2008	2007	2008
Järva	27.27	50.00	37.93	64.29
Pärnu	23.08	56.96	32.26	78.95
Rapla	9.38	32.26	14.81	55.56
Saare	26.47	25.00	57.89	63.16
Võru	31.82	43.90	50.00	64.00

Estonian average	30.52	47.93	42.99	65.10

Table XII shows that in all of these regions WWTP efficiency results are more or less in line with average Estonian values and even the Pärnu region has one of the best WWTPs treatment levels using UWWTD requirements. It should be mentioned that the WWTP efficiency results are much lower using Estonian national requirements. In UWWTD, there are no nutrient removal requirements for WWTPs for which the pollution load is smaller that 10,000 p.e. Pursuant to the Table II and Table III results, showing the average concentrations of Estonian WWTPs effluent pollutants and conformity to the established standards, it is obvious that the biggest problem for WWTPs is TP removal and this problem also carries over to the quality of the receiving water bodies.

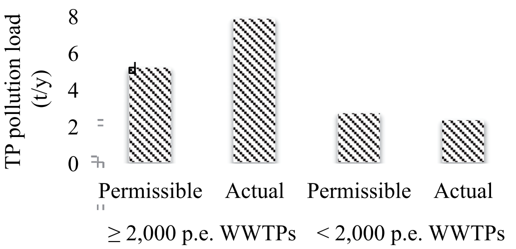

Fig. 11. WWTPs TP pollution load in Pärnu region

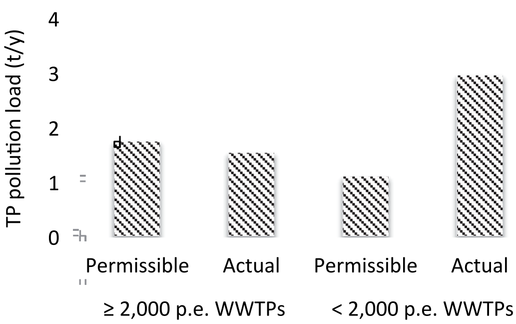

Fig. 12. WWTPs TP pollution load in Saare region

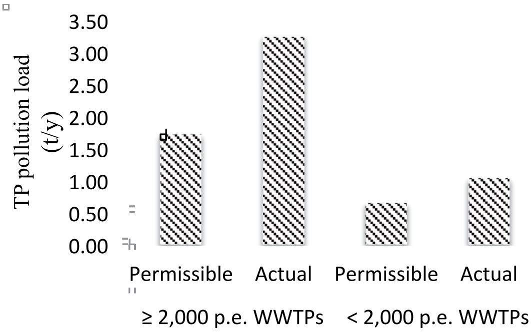

Fig. 13. WWTPs TP pollution load in Järva region

Figs. 11-13 show the WWTP treatment level in certain regions. The permissible TP pollution load shows the permitted pollution load assumption if the WWTP is in conformity with the effluent standards and using the WWTP real flow rate. The actual TP pollution load is calculated using real WWTP effluent concentrations and the real WWTP flow rate. The study results show that WWTPs in the Pärnu, Järva and Rapla regions have serious TP removal problems. In the Järva and Rapla regions, both WWTPs with more than 2,000 p.e. and less than 2,000 p.e. have difficulty being in compliance with the required treatment levels. However, in the Pärnu and Järva regions, the biggest impact is on WWTPs with pollution loads of more than 2,000 p.e. because these WWTPs comprise approx. 77% of all TP pollution in these regions. In the Järva and Rapla regions, the analyses of effluent from WWTPs also indicate some problems with BOD_7 removal, but this is not a wide-ranging problem. In Rapla region, SS removal is also a problem for WWTPs, which means that WWTPs are old and need renovation. In the Saare and Võru regions, the biggest problems are WWTPs with less than 2,000 p.e. treatment efficiency. According to Pachel et al., 2012 [29], discharges from small WWTPs with a load below 2,000 p.e. are relatively high due to pure treatment efficiency. Therefore, most of the small-scale WWTPs require renovation. In the Saare and Võru regions, WWTPs with more than 2,000 p.e. also have some problems with TN removal.

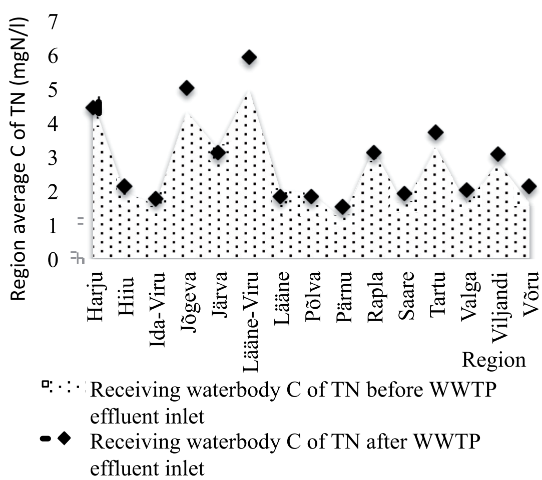

Fig. 14. WWTP effluent TN impact on the receiving water body in Estonia

Fig. 14 unexpectedly shows that although WWTP effluent TP abundance has huge adverse effects on receiving water bodies, TN impact is nevertheless even smaller than BOD_7 impact and the quality of the receiving water body is approx. 9% deteriorated in comparison results before and after the effluent inlet to the water body. Therefore, we can admit that Estonian water bodies are first and foremost P-sensitive and also, according to the WWTPs treatment levels, TN removal is not as comprehensive a problem for Estonian WWTPs. Taking into account the results of Fig. 14 and Tables II and Tables III, the validated TN requirements are quite appropriate when taking into account the TN impact on Estonian water bodies, because the negative result of 9% is probably caused by the few effluent inlets of WWTPs that are not yet in compliance with the TN treatment requirements. Although the wastewater treatment level needs improvement, the wastewater impact on the quality of water bodies is not a comprehensive environmental problem in terms of BOD_7 and TN concentrations. The biggest problem is the TP content in water bodies caused by insufficient TP removal in WWTPs (see Table III) and the P-sensitivity of receiving water bodies. Also, Fig. 15 and Table III show that WWTPs below 10,000 p.e. have the biggest problem with TP removal in Estonia.

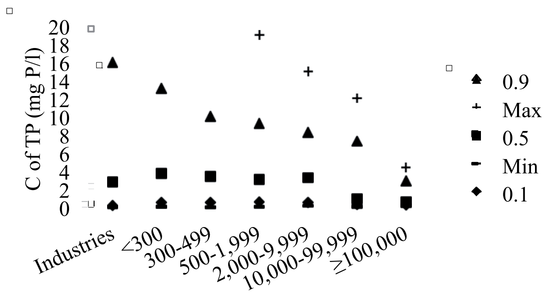

Fig. 15. WWTP effluent variability of TP, also 10- and 90-percentiles.

V. DISCUSSION AND CONCLUSIONS

The study indicates that WWTPs will cause rivers to overload with nutrients due to non-compliance. The reasons for non-compliance have been due to a lack of purification capacity; technical mistakes in construction; the type of the treatment plant that has been chosen does not fit with the local conditions; significant underloading or overloading due to big variability of the inputs; mistakes in exploitation/operation; treatment plant operators lack knowledge and experience, necessary know-how and training; lack of sustainability in the operation of the equipment; the inhabitants do not have enough resources to pay for water services and therefore the water treatment enterprises lack finances for investments. Also, water consumption in the last 15 years has significantly decreased from about 250 l/capita/day to 100 l/capita/day, in small settlements even 50 – 70 l/capita/day, due to a remarkable increase in water service price. The concentration of pollutants in the wastewater is therefore much higher, which makes the treatment more complicated and advanced technology is required. In Estonia, the effluent inlets of WWTPs have the biggest adverse effect in terms of TP content in receiving water bodies. The study results show that after the effluent inlet to the water body, the quality of the receiving water body will deteriorate by approximately 52% in terms of TP concentration. Other contaminants like TN and BOD_7 do not have such a significant adverse effect on the receiving water body and the water quality may deteriorate 9-13% in terms of TN and BOD_7 concentration. Also, the study shows that to minimise the adverse effects of effluent from WWTPs, it is not necessary to establish stricter treatment requirements, because it was apparent that the greater adverse effect was in districts where the WWTP treatment level was not in compliance with the validated requirements. Therefore, we can assume that the effluent adverse effect of effluent on receiving water bodies will reduce considerably after renovation of these WWTPs, or at most at WWTPs outlets. The biggest problem is TP removal efficiency because only 44% of all WWTPs effluent concentrations are in conformity with the established standards in terms of TP. The better TP removal efficiency was in WWTPs with pollution loads of more than 2,000 p.e. These plants have TP removal efficiency of 56%. The average removal efficiency of other pollutants was 69% and 80% for BOD_7 and TN, respectively. Also, the study shows positive feedback in terms of the total pollution load discharged into the environment. Using results from all 774 WWTPs, we can admit that the total pollution load in all contaminants discharged into the environment is much lower than the permissible pollution load that is calculated using established wastewater standards and effluent real flow rate. Of course, if we studied the pollution load of different sized WWTPs separately, we would find that different sized WWTPs have different impact scales and, therefore, it is possible to reduce the total pollution load discharged into the environment in all pollutants and in all WWTP categories. Nonetheless, the cumulative impact of WWTP effluent is not considerable although many WWTPs do not comply with the established requirements. If we consider the fact that many WWTPs are not in compliance with the established requirements, the analysis allows us to conclude that many WWTPs marginally exceed the limit values and also WWTPs that are in compliance with the established requirements discharged notably less pollution into the environment than is actually permitted according to the established standards because total pollution load discharged into the environment is lower than the total permissible pollution load. Despite this, there are now several activities being implemented to reduce the significant inputs of organic pollutants and nutrients into water courses in Estonia. In recent years, important efforts to reduce the phosphorus load have been put into the upgrading of existing WWTPs as well as the construction of new high-grade plants with phosphorus removal, together with the renewal of existing sewers and building new ones in order to connect more settlement areas to public WWTPs. Considering the fact that most Estonian WWTPs are in a renovation phase at the moment, it would be necessary to analyse the WWTP effluent contaminants and nutrient ratio in 2014-2015 following the renovation of these WWTPs. After that, it will be possible to analyse contiguous data that were discovered during this study conducted before the WWTPs renovation phase with data collected from 2014-2015 after the renovation of the WWTPs.

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PAPER IV

Niine, R., Loigu, E., Pachel, K. (2012). Wastewater impact on the quality of waterbodies in Estonia. In: Advances in Environment, Computational Chemistry & Bioscience: 10th WSEAS International Conference on Environment, Ecosystems and Development (EED '12), Montreaux, Switzerland, 29-31 December 2012. (Ed.) Prof. S. Oprisan et.al. Montreaux, Switzerland: WSEAS Press, 2012, 175–180.

Wastewater impact on the quality of waterbodies in Estonia

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Abstract: Wastewater is one of the biggest causes of point source pollution and has a negative effect on the quality of waterbodies. In Estonia, all waterbodies are categorised as sensitive waterbodies according to European Council directive 91/271/EEC of 21 May 1991 for urban wastewater treatment. Therefore, all Estonian wastewater treatment plants have much higher treatment standards than most of the other European regions. The aim of this study was to analyse exactly how much wastewater effluent impacts upon the receiving waterbody quality in Estonia and whether stricter wastewater treatment requirements are needed to protect Estonian waterbodies. Also, during this study, research was conducted into what kind of wastewater pollutants have the biggest adverse effect on waterbodies and what kind of steps Estonia needs to take to improve this.

Key-Words: wastewater, treatment plant, treatment level, effluent, receiving waterbody, pollution load.

1. Introduction

Estonian waterbodies are quite vulnerable to eutrophication due to their small catchments areas and low flow rate. The stream system is relatively dense; the network of rivers longer than 10 km is 0.23 km/km^2. Most rivers are short and there are only 10 rivers longer than 100 km, with 13 rivers having a mean annual average flow exceeding 10 m^3. The total runoff from Estonian rivers in an average year is 11.7 cubic kilometres, but is only 5.5 cubic kilometres in very dry (95% probability) years. The upper courses of Estonian rivers are particularly scarce of water and in low water periods the flow can be almost zero [1, 2]. This situation causes problems in using rivers as recipients for wastewater discharge because of insufficient dilution [3–5]. Several studies refer to the fact that most of the P tends to be retained within river systems during low-flow periods i.e. at times of greatest eutrophication risk [6–9]. Therefore, Estonian regulations impose stricter wastewater treatment requirements than what have been set by the European Council directive 91/271/EEC of 21 May 1991 for urban wastewater treatment (UWWTD). The UWWTD's main goal is to protect the environment from the adverse effects of urban wastewater discharges and discharges from certain industrial sectors [10]. If the UWWTD requirements are not sufficient to achieve a satisfactory status for waterbodies and discharge is one of the main causes of point source pollution for waterbodies, additional wastewater treatment will be required [11, 12]. Table 1 gives an overview of different wastewater treatment requirements.

Table 1. Estonian National (EE) and European Union (EU) Wastewater Discharge Standards

	Biochemical oxygen demand (BOD_7), mgO_2/l	Chemical oxygen demand (COD), mgO_2/l	Suspended solids (SS), mg/l	Total phosphorus (TP), mgP/l	Total nitrogen (TN), mgN/l
≥100,000 p.e.					
EE	15	125	15	1	10
EU	25	125	35	1	10
10,000–99,000 p.e.					
EE	15	125	15	1	15
EU	25	125	35	2	15
2,000–9,999 p.e.					
EE	15	125	25	1.5	-
EU	25	125	35	-	-
500–1,999 p.e.[1]					
EE	25	125	25	2	-
EU	25	125	35	-	-
<500 p.e.[1]					
EE	25	125	25	-	-
EU	25	125	35	-	-

[1]EE and EU do not establish common standards. These standards are developed taking into account the aim of directives and requirements given in the permits of water special use.

Also, the Baltic Sea countries have adopted an action plan to achieve a satisfactory ecological status for the Baltic Sea by 2021 [13]. The eutrophication of surface waters and the sea enhanced by the anthropogenic input of nitrogen and phosphorus from point and diffuse sources is one of the main environmental concerns in the Baltic Sea Region [14–19], and globally [20, 21]. One of the main issues covered by the Baltic Sea Action Plan is the further reduction of nutrient inputs in order to limit the eutrophication of waterbodies. In this study, it is analysed whether the stricter treatment requirements are sufficient to protect waterbodies from the adverse effect of effluent.

2. Methodology

During the study, a total of 773 different wastewater treatment plants (WWTPs) were analysed, from which 67 serve the agglomeration areas with a pollution load of 2,000 p.e. or more and all other WWTPs serve the agglomeration areas where the pollution load is less than 2,000 p.e. It should be mentioned that Estonia has a total of 59 agglomeration areas with 2,000 p.e. or more but all the WWTPs that serve these areas must comply with 2,000 p.e. or more agglomeration area requirements. Therefore, this study covers all Estonian WWTPs that serve the agglomerations with a pollution load of 2,000 p.e. or more and almost all smaller WWTPs that serve agglomeration areas with less than 2,000 p.e. and even the WWTPs that do not serve an agglomeration area at all and are built as individual WWTPs. The analysis is based on 2,251 single sample results, which were taken from different WWTPs effluents to analyse BOD_7, SS, TN, TP and COD concentrations and additionally 1,198 samples results, which were taken from the appropriate upper and lower courses of receiving waterbodies from WWTP effluent inlet.

The analysis on the wastewater samples was carried out in accredited laboratories in Estonia using standardised methodology SFS 5505:1988 for TN, EVS-EN ISO 6878:2004 for TP, ISO 5815-1:2003 for BOD_7, EVS-EN 872:2005 for SS and ISO 6060:1989 for COD. Additionally, all samples were taken by qualified samplers who have been granted attestation and all samples were analysed in accredited laboratories. All receiving waterbody samples consist of three samples – surface water sample before WWTPs effluent inlet to the receiving waterbody, surface water sample after WWTPs effluent inlet and WWTP effluent sample. BOD_7, SS, TN, TP and COD were also analysed in all of these samples. It must also be mentioned that the upper course waterbody sample was taken approximately 500 m before the effluent inlet to the waterbody and the lower course sample was taken in the place where wastewater is well mixed with surface water and the real place depended on all the waterbody and wastewater characteristics, such as turbulence, water flow rate, etc. Therefore, the sample was not taken from the place next to the WWTP effluent inlet to the waterbody.

3. Analyse of the effluent pollution

From 2007–2008, which was the sampling period, the average efficiency of the WWTPs (using BOD_7, TP, TN, SS and COD concentrations) in 2008 was 48% according to the Estonian national requirements and 65% according to the UWWTD requirements. These results show that it is important to analyse the wastewater impact on waterbodies, while considering whether a single WWTP is in accordance with the Estonian national requirements.

Table 2. Estonian WWTPs effluent pollutants average values, in 2008

(BOD_7), mgO_2/l	(TP), mgP/l	(TN), mgN/l	(SS), mg/l	(COD), mgO_2/l
11.9	3.4	14.9	18.3	71.9

Considering the effluent pollutant concentrations of WWTPs, in this study the impact of every single WWTP effluent on certain waterbody quality was analysed.

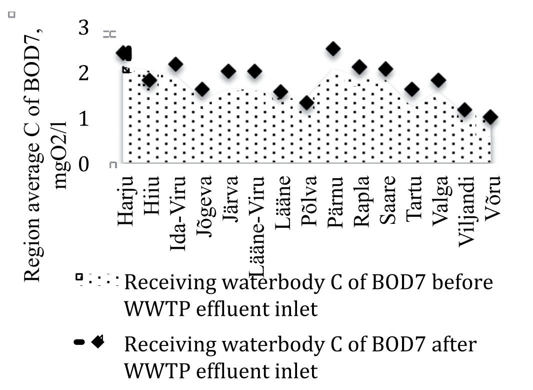

Fig. 1. WWTP effluent average BOD_7 impact on the receiving waterbody in Estonia

As Fig. 1 shows, in today's WWTPs conditions, the WWTPs effluent inlet impacts the receiving waterbody quality. The receiving waterbody quality has deteriorated approximately 13% since the WWTP effluent inlet to the receiving waterbody.

Taking into account the results in Fig. 1 and even if we consider that the WWTP effluent adversely affects the receiving waterbody, the absolute values show that the main effluent impact is not significant enough to change the status of the receiving waterbody. The waterbody has a good status in terms of BOD_5 if the BOD_5 concentration varies from different watercourses from 1.8–3.5 mgO_2/l [22] and as we can see in the Fig. 1, the waterbodies average BOD_7 concentrations vary after WWTP effluent discharge from 1.0–2.5 mgO_2/l, which do not exceed the limit values established by the legal document. Therefore, we may conclude that BOD_7 is not the biggest problem for the quality of Estonian waterbodies. However, the small WWTPs (below 2000 p.e.) are largely not in accordance with the BOD_7 removal requirements.

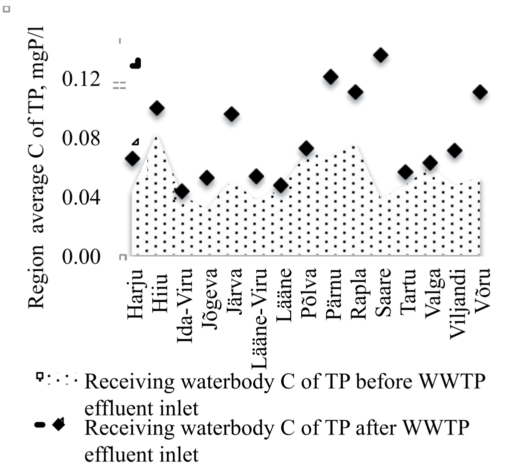

Fig. 2. WWTP effluent average TP impact on the receiving waterbody in Estonia

Estonian waterbodies are sensitive and have a high eutrophication risk. The main element limiting primary production and thus the eutrophy of inland waterbodies is phosphorus [23]. Therefore, Fig. 2 also shows that the WWTP effluent TP concentration has much a higher impact on the waterbody than BOD_7 concentration. The study shows that the receiving waterbody quality has deteriorated by as much as 52% since the WWTP effluent inlet to the waterbody.

The TP values show that there is strong impact on the status of the receiving waterbody. The waterbody has good status in terms of TP, if TP concentration is between 0.04–0.08 mgP/l [22] and as we can see in the Fig. 2 the average TP concentrations of waterbodies varies after WWTP effluent discharges from 0.04–0.14 mgP/l. The TP concentration between >0.1–0.12 mgP/l means that the waterbody status is poor and below 0.12 mgP/l the waterbody status is bad.

As in Fig. 2, the biggest impact occurs in the Järva, Pärnu, Rapla, Saare and Võru regions.

Table 3. WWTP impact on the receiving waterbody in the Pärnu and Järva regions

Receiving waterbody	Waterbody C of TP before WWTP effluent inlet	Waterbody C of TP after WWTP effluent inlet
Pärnu region		
Uruste	0.27	0.32
Vaheliku	0.29	0.95
Lähkma	0.04	0.28
Ura	0.08	0.11
Järva region		
Lokuta	0.04	1.20
Navesti	0.33	0.80
Vanavälja	0.28	0.36
Järva-Jaani	0.03	1.20
Pärnu	0.05	0.07

Table 3 gives some examples of the WWTP effluent impact on receiving waterbodies in the Järva and Pärnu regions. The biggest adverse effect is small tributaries and main ditches, such as Lokuta, Vanavälja, and Järva-Jaani, where the flow rate is very low all-year round in the Järva region. Therefore, even a small amount of discharged pollution has a significant adverse effect on the waterbody. At the same time, wastewater from the WWTPs discharged into the Lokuta river, Navesti river, Vanavälja main ditch and Järva-Jaani ditch is not treated as required. And as we can see in Table 3, all of these WWTPs for which the treatment level is not in conformity with the requirements influence the status of the waterbody. On the other hand, Pärnu river, which is one of the biggest rivers in Estonia and has several tributaries, does not have any adverse effect or has a minimal adverse effect from the effluent inlet to the waterbody, although there are also WWTPs that are not in conformity with the requirements. The mean annual average flow rate of Pärnu river is 50–65 m^3/s in the lower course [24] and this is the reason why the adverse effluent effect of WWTPs is minimal. In the Järva region, the waterbodies are also quite vulnerable because of intensive farming and the flow rate is very low in most of the receiving waterbodies. Therefore, even a very marginal pollution load may cause problems for the water quality.

In the Pärnu region, it is possible to indicate that the biggest adverse effect is on smaller waterbodies, mostly minor streams or very small rivers, where the flow rate is low, e.g. Ura. Also, WWTP treatment is not at the required level in many places, which causes an adverse effect.

Table 4. WWTP efficiency (using BOD_7, TN, TP, SS and COD concentrations in WWTP effluent) in Järva, Pärnu, Rapla, Saare and Võru regions.

	WWTP efficiency, %			
	Estonian national requirements		UWWTD requirements	
Region	2007	2008	2007	2008
Järva	27.27	50.00	37.93	64.29
Pärnu	23.08	56.96	32.26	78.95
Rapla	9.38	32.26	14.81	55.56
Saare	26.47	25.00	57.89	63.16
Võru	31.82	43.90	50.00	64.00
Estonian average	30.52	47.93	42.99	65.10

Table 4 shows that in all of these regions WWTP efficiency results are more or less in line with average Estonian values and even the Pärnu region has one of the best WWTPs treatment level using UWWTD requirements. It should be mentioned that the WWTP efficiency results are much lower using Estonian national requirements. In UWWTD, there are no nutrient removal requirements for WWTPs for which pollution load is smaller that 10,000 p.e. Pursuant to Table 2 results, showing the average concentrations of Estonian WWTPs effluent pollutants, it is obvious that the biggest problem for WWTPs is TP removal and also this problem carries over to the quality of receiving waterbodies.

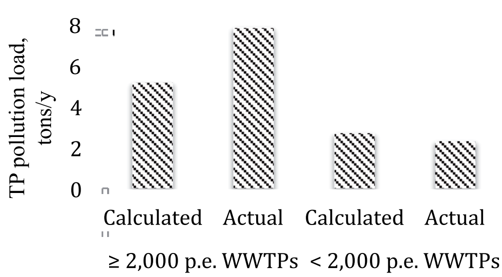

Fig. 3. WWTPs TP pollution load in Pärnu region

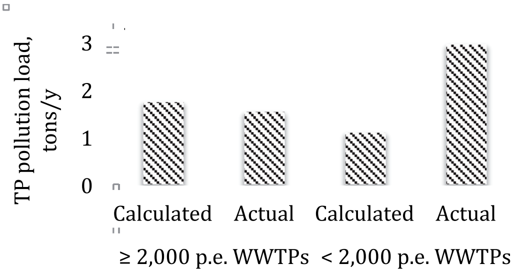

Fig. 4. WWTPs TP pollution load in Saare region

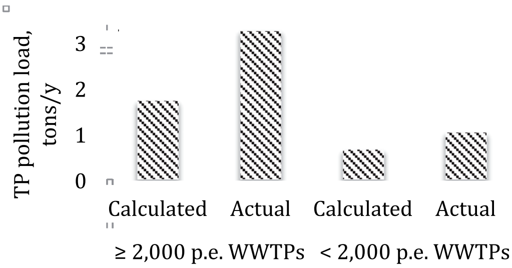

Fig. 5. WWTPs TP pollution load in Järva region

Figs. 3–5 show the WWTP treatment level in certain regions. The calculated TP pollution load shows the allowed pollution load assumption if the WWTP is in conformity with the effluent standards and using the WWTP real flow rate. The actual TP pollution load is calculated using real WWTP effluent concentrations and the real WWTP flow rate. The study results show that WWTPs in the Pärnu, Järva and Rapla regions have serious TP removal problems. In the Järva and Rapla regions, both WWTPs with more than 2,000 p.e. and less than 2,000 p.e. have problems being in compliance with the required treatment levels. However, in the Pärnu and Järva regions, the biggest impact is on WWTPs with a pollution load of more than 2,000 p.e. because these WWTPs form approx. 77% of all TP pollution in these regions. In the Järva and Rapla regions, the analyses of effluent from WWTPs also indicate some problems with BOD_7 removal, but this is not a comprehensive problem. In Rapla region, SS removal is also a problem for WWTPs, which means that WWTPs are old and need renovation. In the Saare and Võru regions, the biggest problems are WWTPs with less than 2,000 p.e. treatment efficiency. According to Pachel et al., 2012 [25], discharges from small WWTPs with a load below 2,000 p.e. are relatively high due to pure treatment efficiency. Therefore, most of the small-scale WWTPs need renovation. In the Saare and Võru regions, WWTPs with more than 2,000 p.e. have some problems with TN removal.

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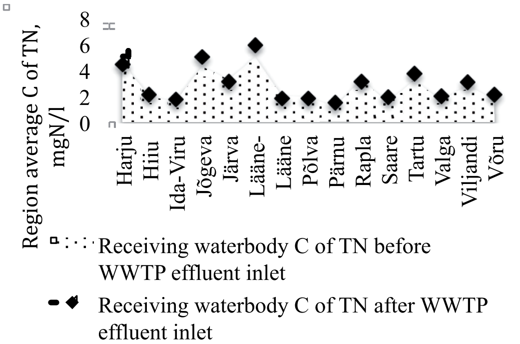

Fig. 6. WWTP effluent TN impact on the receiving waterbody in Estonia

Fig. 6 unexpectedly shows that although WWTP effluent TP abundance has huge adverse effects on receiving waterbodies, TN impact is nevertheless even smaller than BOD_7 impact and the quality of the receiving waterbody is approx. 9% deteriorated in comparison results before and after the effluent inlet to the waterbody. Therefore, we can admit that Estonian waterbodies are first and foremost P-sensitive and also according to the WWTPs treatment levels, TN removal is not as comprehensive a problem for Estonian WWTPs. Taking into account the results of Fig. 6 and Table 2, the validated TN requirements are quite appropriate taking into account the TN impact on Estonian waterbodies, because the negative result of 9% is probably caused by the few effluent inlets of WWTPs that are not yet in conformity with the TN treatment requirements. Although the wastewater treatment level needs improvement, the wastewater impact on the quality of waterbodies is not a comprehensive environmental problem in terms of BOD_7 and TN concentrations. The biggest problem is the TP content in waterbodies caused by insufficient TP removal in WWTPs and the P-sensitivity of receiving waterbodies. Also, Fig. 7 shows that WWTPS below 10 000 p.e. have the biggest problem with TP removal in Estonia.

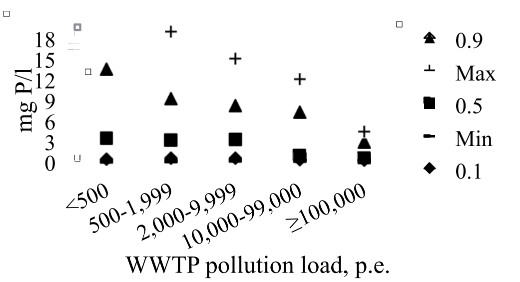

Fig. 7. WWTP effluent variability of TP, also 10- and 90-percentiles.

4. Conclusions

The study indicates that due to non-compliance WWTPs will cause rivers to overload with nutrients. The reasons for non-compliance have been due to a lack of purification capacity and operational and maintenance problems. In Estonia, the effluent inlets of WWTPs have the biggest adverse effect in terms of TP content in receiving waterbodies. The study results show that after the effluent inlet to the waterbody, the quality of the receiving waterbody will deteriorate by approximately 52% in terms of TP concentration. Other contaminants like TN and BOD_7 do not have such a significant adverse effect on the receiving waterbody and the water quality may deteriorate 9–13% in terms of TN and BOD_7 concentration. Also, the study shows that to minimise the adverse effects of effluent from WWTPs, it is not necessary to establish stricter treatment requirements, because it was apparent that the biggest adverse effect was in districts where the WWTP treatment level was not in compliance with the validated requirements.

In Estonia, there are now several activities being implemented to reduce the significant inputs of organic pollutants and nutrients into water courses. In recent years, important efforts to reduce the phosphorus load have been put into the upgrading of existing WWTPs as well as the construction of new high-grade plants with phosphorus removal. Considering the fact that most of the Estonian WWTPs are in a renovation phase at the moment, it would be necessary to analyse the WWTPs effluent contaminants and nutrient ratio following the renovation of these WWTPs in 2014–2015. After that, it will be possible to analyse contiguous data that were discovered during this study conducted before the WWTPs renovation phase with data collected from 2014–2015 after the renovation of the WWTPs.

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APPENDIX II CURRICULUM VITAE

1. Personal data

Name	Raili Niine
Date and place of birth	16/05/1980, Kuressaare, Estonia

2. Contact information

Address	Narva mnt 155-3, 51009, Tartu, Estonia
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3. Education

Educational institution	Graduation year	Education (field of study/ degree)
Tallinn University of Technology	2004	Master degree - speciality: Chemical and Environmental Protection Technology
Tallinn University of Technology	2002	Bachelor degree - speciality: Chemical and Environmental Protection Technology
Kuressaare Gymnasium	1998	Secondary education

4. Language competence/skills

Estonian	Native
English	Good
Russian	Average

5. Professional Employment

Period	Organisation	Position
2007- ...	Ministry of the Environment	Advisor in Water Department
2011-2012	Estonian Environmental Research Centre	Board Member
2005-2012	Kuressaare Veevärk AS	Board Member
2005-2011	Äri-Info OÜ	Lecturer
2005-2011	Bi-Info AS	Lecturer
2003-2007	Ministry of the Environment	Senior Officer in Water Department

6. Special Courses

Period	Educational Organisation	Description
2010-2011	Government Office	Management training in public service NEWTON II
2010	Tallinn University	Lecturer training
2010; 2011	ATAK	Ethics in public service
2010	Office of the Chancellor of Justice	Fundamental rights in legislation
2010	IAP	Management training
2005	ATAK	European Union policy development
2005	Nordic Innovation Centre, Brussels	Chemical and Environmental Sampling – Quality through Accreditation, Certification and Industrial Standards
2003	Wallonian Ministry of Foreign Affairs, Belgium	Training in field of environment protection

7. Defended theses

Master theses: Analysis of Estonian Oil Shale Pyrolysis with Thermogravimetric Mass Spectrometric Analyser, 2004.

Bachelor theses: Vasalemma River Basin Management Plan, 2002.

8. Main areas of scientific work/Current research topics

The regulations of wastewater treatment in Estonia and at EU level, water protection, public water supply and sewage, water companies, and water price.

9. Scientific work

Publications and presentations:

Niine, R.; Loigu, E.; Pachel, K. (2013). Compliance of wastewater treatment plants in Järva County with the EU urban wastewater treatment directive and Estonian national requirements. European Scientific Journal, 3, 365–375.

Niine, Raili; Loigu, Enn; Tang, Walter Z. (2013). Development of Estonian nutrient discharge standards for wastewater treatment plants. Estonian Journal of Engineering, 19, 152–168.

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Niine, R., Loigu, E., Pachel, K. (2012). Wastewater impact on the quality of waterbodies in Estonia. In: Advances in Environment, Computational Chemistry & Bioscience: 10th WSEAS International Conference on Environment, Ecosystems and Development (EED '12), Montreaux, Switzerland, 29-31 December 2012. (Ed.) Prof. S. Oprisan et.al. Montreaux, Switzerland: WSEAS Press, 2012, 175–180.

Published books:

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APPENDIX III ELULOOKIRJELDUS

1. Isikuandmed

Ees- ja perekonnanimi	Raili Niine
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3. Hariduskäik

Õppeasutus	Lõpetamise aeg	Haridus (eriala/kraad)
Tallinna Tehnikaülikool	2004	Tehnikateaduste magistri kraad Eriala: keemia- ja keskkonnakaitsetehnoloogia
Tallinna Tehnikaülikool	2002	Tehnikateaduste bakalaureuse kraad Eriala: keemia- ja keskkonnakaitsetehnoloogia
Kuressaare Gümnaasium	1998	Keskharidus

4. Keelteoskus

Keel	Tase
eesti keel	emakeel
inglise keel	hea
vene keel	keskmine

5. Teenistuskäik

Töötamise aeg	Tööandja nimetus	Ametikoht
2007-...	Keskkonnaministeerium	Veeosakonna nõunik
2011-2012	Eesti Keskkonnauuringute Keskus OÜ	Nõukogu liige
2005-2012	AS Kuressaare Veevärk	Nõukogu liige
2005-2011	OÜ Äri-Info	Lektor
2005-2011	AS Bi-Info	Lektor
2003-2007	Keskkonnaministeerium	Veeosakonna spetsialist

6. Täiendõpe

Õppimise aeg	Täiendõppe läbiviija	Kirjeldus
2010-2011	Riigikantselei	Avaliku teenistuse tippjuhtide koolitus NEWTON II
2010	Tallinna Ülikool	Sisekoolitaja väljaõpe
2010; 2011	Avaliku Teenistuse Arendus- ja Koolituskeskus	Avaliku teenistuse eetika
2010	Õiguskantsleri Kantselei	Põhiõigused õigusloomes
2010	IAP	Spetsialistist juhiks koolitus
2005	Avaliku Teenistuse Arendus- ja Koolituskeskus	Euroopa Liidu poliitikate kujundamine
2005	Nordic Innovation Centre, Brüssel	Keemia- ja keskkonnaalaste proovide võtmine – kvaliteet läbi akrediteerimise, sertifitseerimise ja standardite
2003	Walloonia Välisministeerium, Belgia	Keskkonnakaitsealane koolitus

7. Kaitstud lõputööd

Magistritöö: Eesti põlevkivi pürolüüsi analüüsimine termogravimeetrilise mass-spektromeetrilise analüsaatoriga, 2004.

Bakalaureusetöö: Vasalemma jõe valgala veemajanduskava projekt, 2002.

8. Teadustöö põhisuunad

Asulareovee puhastamise regulatsioon Eestis ja Euroopa Liidus, veekaitse, ühisveevärk- ja kanalisatsioon, vee-ettevõtted, vee hind.

9. Teadustegevus

Publikatsioonid ja ettekanded

Niine, R.; Loigu, E.; Pachel, K. (2013). Compliance of wastewater treatment plants in Järva county with the EU urban wastewater treatment directive and Estonian national requirements. European Scientific Journal, 3, 365 - 375.

Niine, Raili; Loigu, Enn; Tang, Walter Z. (2013). Development of Estonian nutrient discharge standards for wastewater treatment plants. Estonian Journal of Engineering, 19, 152 - 168.

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Avaldatud trükised

Niine, R.; Sinikas, N.; Zahharov, A.; Endjärv, E.; Ennet, P.; Tooming, A. (2010). Asulareovee puhastamise direktiivi nõuete täitmine Eestis. Tallinn: Keskkonnateabe Keskus.

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