# 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[1] 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.

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

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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)<br>≥ 2,000 p.e. WWTPs | <br>< 2,000 p.e. WWTPs |
|---|---|---|
| TP | 74.84 | 29.60 |
| TN | 981.51 | 194.42 |
| $BOD_7$ | 687.07 | 404.92 |

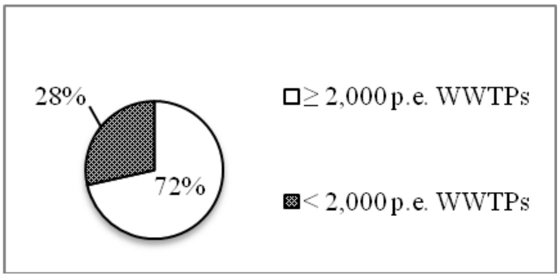

Fig.1. Origin of TP pollution load

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.

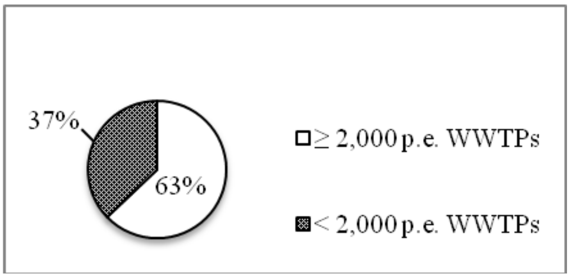

Fig.2. Origin of $BOD_7$ pollution load

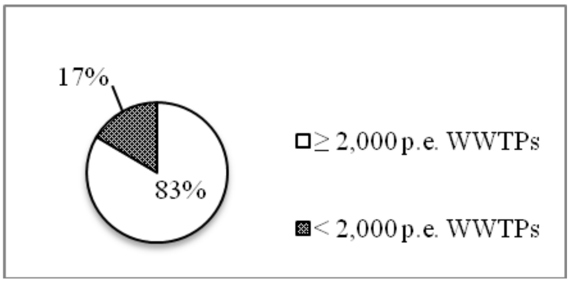

Fig.3. Origin of TN pollution load

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.

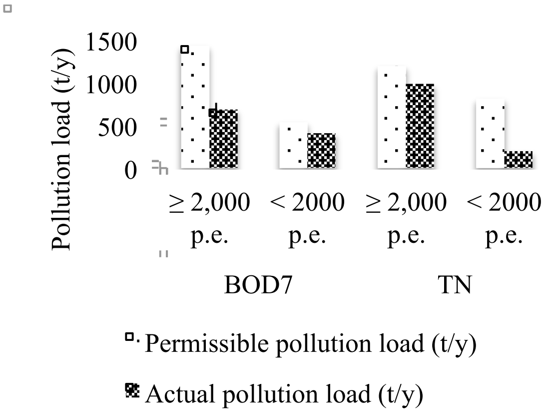

Fig.4. Actual and permissible $BOD_7$ and TN pollution loads discharged into the environment by 774 WWTPs.

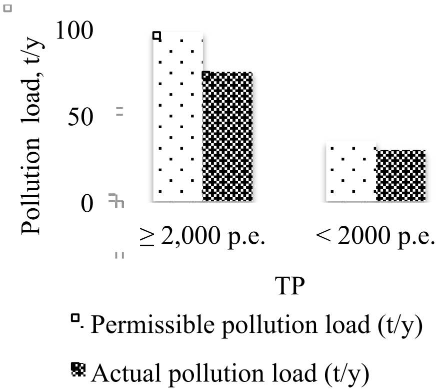

Fig.5. Actual and permissible TP pollution load discharged into the environment by 774 WWTPs.

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.

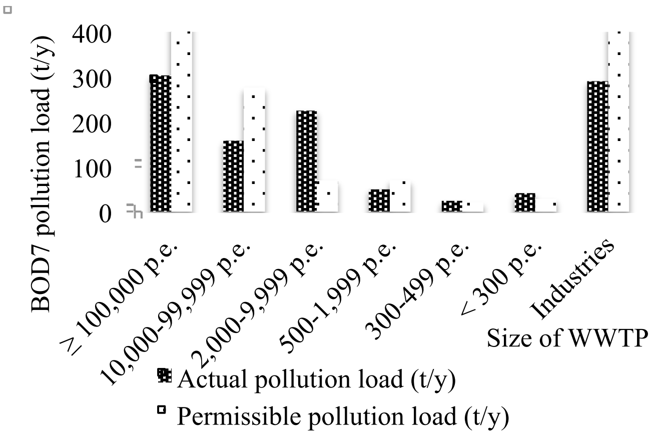

Fig.6. $BOD_7$ actual and permissible pollution load distribution

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.

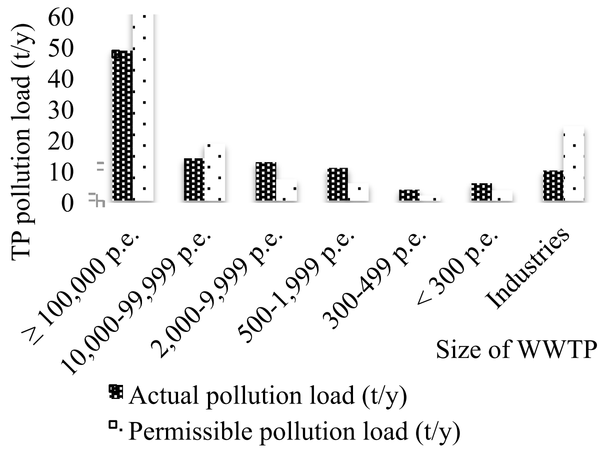

Fig.7. TP actual and permissible pollution load distribution

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.

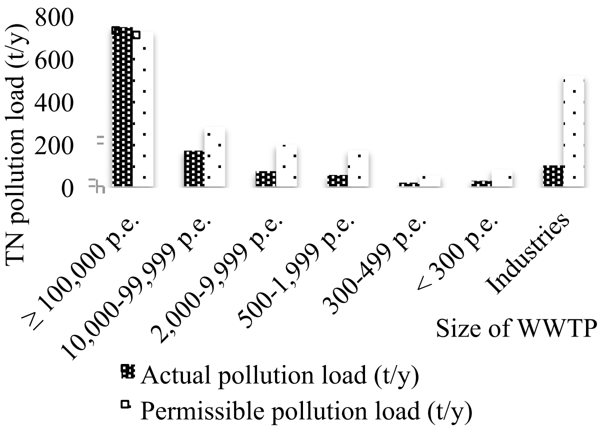

Fig.8. TN actual and permissible pollution load distribution

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.

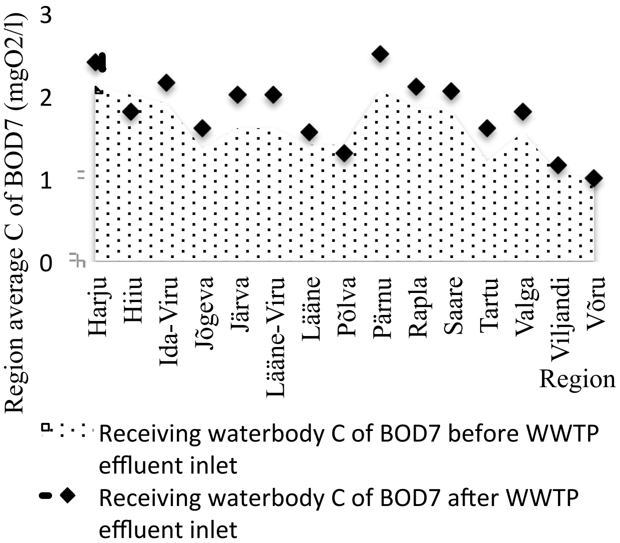

Fig. 9. WWTP effluent average $BOD_7$ impact on the receiving water body in Estonia

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.

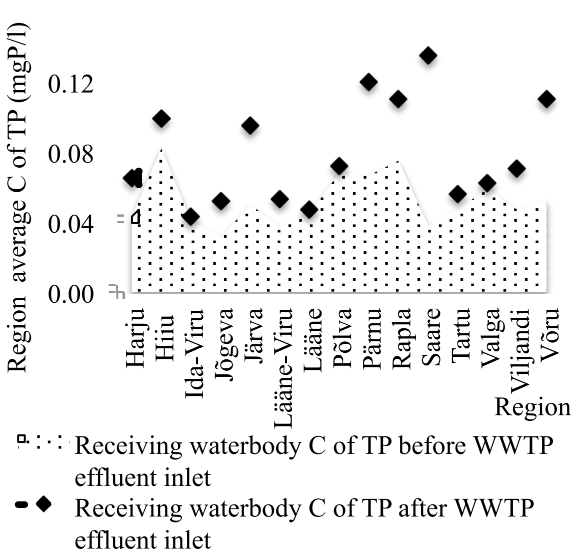

Fig. 10. WWTP effluent average TP impact on the receiving water body in Estonia

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.

| | 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 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.

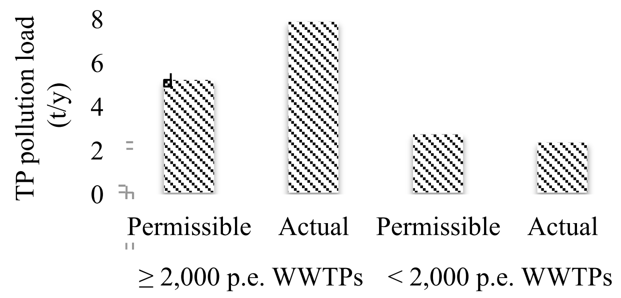

Fig. 11. WWTPs TP pollution load in Pärnu region

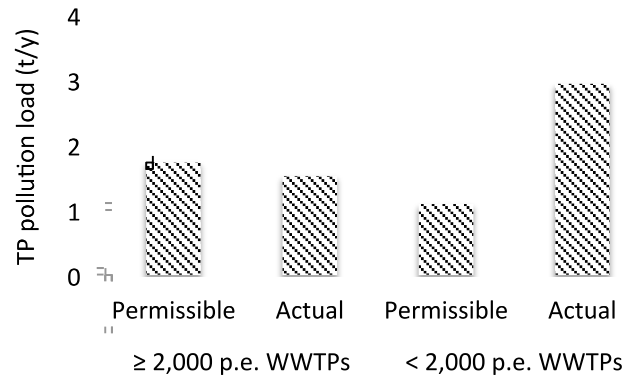

Fig. 12. WWTPs TP pollution load in Saare region

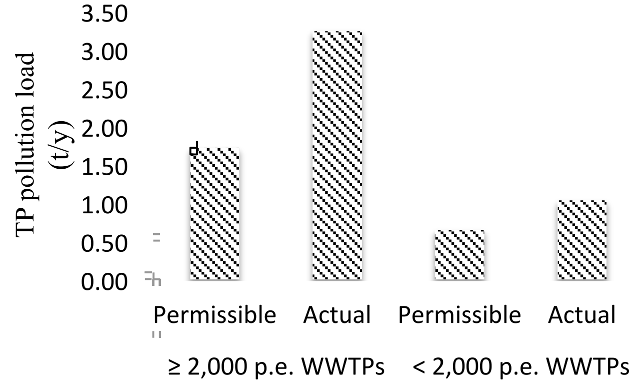

Fig. 13. WWTPs TP pollution load in Järva region

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.

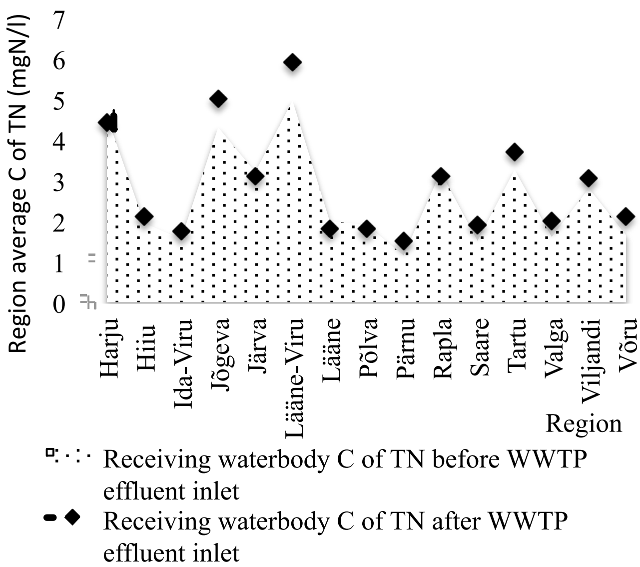

Fig. 14. WWTP effluent TN impact on the receiving water body in Estonia

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.

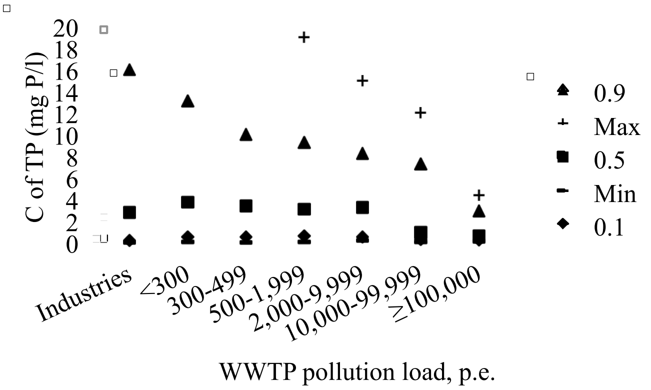

Fig. 15. WWTP effluent variability of TP, also 10- and 90-percentiles.

## 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.

## ACKNOWLEDGMENTS

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