Project Deliverable 3.1

SMALL- AND MIDDLE-SIZED WWTP WASTE WATER QUALITY ASSESSMENT AND ITS INFLUENCE ON SLUDGE QUALITY

TABLE OF CONTENTS

INTRODUCTION

For this project small- and middle-sized wastewater treatment plants (WWTPs) were studied by all project partners.

The Klaipeda WWTP is the main biological sewage treatment plant in Klaipeda, build in 1998 with a capacity of 305.333 PE based on the challenge of total nitrogen amount. Wastewater and sludge quality reflect that it is household and industrial wastewater from cigarette production, paper mill, wood timber, wood processing, furniture as well as food production and service companies which is treated at Klaipeda WWTP.

Goleniów WWTP is a biological WWTP situated in Goleniów city, West Pomeranian District, North-western Poland. It was built in 1994 and rebuilt in 2011-2012 with the current capacity of 63 805 PE. Wastewater and sludge quality reflect that it is mostly household wastewater with some industrial sewage from the sectors of plastics production, meat processing, car washes and sewage delivered from septic tanks which is treated at Goleniów WWTP.

Rønne WWTP is the largest of the seven biological WWTPs on Bornholm. It was built in 1995 with capacity of 60 000 PE. Wastewater and sludge quality reflect that it is mostly household wastewater without much industry, except the slaughterhouse, the hospital, and a few metal processing industries in Rønne.

In Sweden two treatment plants were studied Lyby WWTP in Hørby and Ormanäs WWTP in Höör which are the two largest WWTPs operated by Mittskåne Vatten. Lyby WWTP was built in 1976 and was rebuilt in 1988 to include treatment of nitrogen. Lyby WWTP has a capacity of 18000PE. Ormanäs WWTP was built in 1978 and expanded twice to include treatment of nitrogen and further pre-sedimentation etc. It has a capacity of 15000PE. Wastewater and sludge quality at both Lyby and Ormanäs WWTP reflect that mainly household wastewater is treated in the WWTPs – except for a slaughterhouse in Hørby whose wastewater is treated at Lyby WWTP.

1. METHODS FOR WASTEWATER & SLUDGE QUALITY ASSESSMENT

1.1. Bornholms Energy & Supply

Wastewater analysis

At Rønne WWTP inlet and outlet samples were taken as 24-hour flow proportional samples at programmable sampling stations. According to the municipal permit only organics and nutrients were analysed - chemical oxygen demand (COD), biological oxygen demand (BOD_5), total nitrogen (N_{tot}), and total phosphorous (P_{tot}) (see Table 1). All collected samples were sent to a certified laboratory (Eurofins) for analysis. Internal analysis is carried through more frequently, as well as on-line monitoring of nitrate, ammonium, oxygen, and phosphorus.

Table 1 Sampling frequencies, analytical method used and detection limits for the compounds in the assessment of wastewater quality.

Parameter	Inlet	Outlet	Analytical method	Detection limit
COD	1/month	2 /month	ISO 15705	5 mg/l
BOD_5	1/month	2/month	DS/EN 1899-1	0,5 mg/l
P_{tot}	1/month	2/month	DS EN ISO 6878:2004	0,01 mg/l
N_{tot}	1/month	2/month	DS EN ISO 11905-1:1998	0,05 mg/l

Threshold limits for wastewater

The threshold limits for Rønne WWTP are seen below in Table 2.

Table 2 Threshold limits as set by the municipality for concentrations of compounds in the effluent.

Parameter	Threshold limit (mg/l)	Type
COD	75	Yearly average
BOD_5	15	Yearly average
N_{tot}	8	Yearly average
P_{tot}	1,5	Yearly average

Sludge analysis

For sludge a sample is collected every month by the certified laboratory (ALS). The samples are mixed and sent for analysis every third month. The percentage of dry matter (DM) and concentrations of nutrients, metals, and organic micropollutants are analysed. Table 3 shows the used analytical methods and threshold values for each parameter.

Table 3 Parameters, Limit values, analytical method and associated detection limit, in the assessment of sludge quality.

Parameter	Threshold value	Analytical method	Detection limit
Dry Matter (%)		DS 204:1980	-
N_{tot}		DS/EN 16168:2012	-
P_{tot}		DS 259:2003+DS/EN 16170:2016	-
K_{tot}		DS 259:2003+DS/EN 16170:2016	-
S		DS 259:2003+DS/EN 16170:2016	-
Hg	0.8 mg/kg DM / 200 mg/kg P	DS 259:2003+DS/EN 16170:2016	-
Pb	120 mg/kg DM / 10.000 mg/kg P	DS 259:2003+DS/EN 16170:2016	-
Zn	4.000 mg/kg DM	DS 259:2003+DS/EN 16170:2016	-
Ni	30 mg/kg DM / 2.500 mg/kg P	DS 259:2003+DS/EN 16170:2016	-
Cr	100 mg/kg DM	DS 259:2003+DS/EN 16170:2016	-
Cu	1.000 mg/kg DM	DS 259:2003+DS/EN 16170:2016	-
Cd	0.8 mg/kg DM / 100 mg/kg P	DS 259:2003+DS/EN 16170:2016	-
LAS	1300 mg/kg DM	AK87 - LC/UV	-
PAHsum	3 mg/kg DM	AK87 - GC/MS/SIM	-
NPE	10 mg/kg DM	AK87 - GC/MS/SIM	-
DEPH	50 mg/kg DM	AK87 - GC/MS/SIM	-

1.2. KLAIPEDA UNIVERSITY

Wastewater analysis

At Klaipeda WWTP wastewater sampling was performed in accordance with ISO 5667-10:2011. The methods for determination of the main sewage quality parameters are presented in Table 4.

Table 4 Analytical method used and detection limits for the compounds in the assessment of wastewater quality.

Parameter	Threshold value	Analytical method	Detection limit
COD		ISO 15705:2002	4.95 mgO_2/l
BOD_7		LAND 47-1:2007, LAND 47-2:2007	0.75 mgO_2/l
P_{total}		LAND 58-2003	0.09 mg/l
N_{total}		LAND 84-2006, LST EN ISO 13395-2000, LST EN ISO 11905-1:2000	1.02 mg/l

Threshold limits for wastewater

The threshold values for Klaipeda WWTP are seen below in Table 5.

Table 5 Threshold limits of compounds in the effluent. MAC – maximum allowable concentration.

Parameter	Threshold limit / MAC (mg/l)	Type
COD	125	Daily average
BOD7	17	Daily average
N_{tot}	10	Annual average
P_{tot}	0,5	Annual average

Sludge analysis

The sludge sampling at Klaipeda WWTP is performed in accordance to Table 6 below.

Table 6 Parameters, Limit values, analytical method and associated detection limit, in the assessment of sludge quality at Klaipeda WWTP.

Parameter	Limit value	Analytical method	Detection limit
Dry Matter (%)	n/a	LST EN 15934:2012, A metodas	0.3%
N_{tot}	n/a	LST EN 13342:2002	11.9 mg/kg
P_{tot}	n/a	LAND 78-2006	11.2 mg/kg

Hg	n/a	LST CEN/TS 16175-1:2013	0.06 mg/kg
Pb	n/a	LST CEN/TS 16172:2013	0.4 mg/kg
Zn	n/a	LST CEN/TS 16188:2012	6.0 mg/kg
Ni	n/a	LST CEN/TS 16172:2013	0.8 mg/kg
Cr	n/a	LST CEN/TS 16172:2013	0.2 mg/kg
Cu	n/a	LST CEN/TS 16188:2012 LST CEN/TS 16172:2013	0.6 mg/kg
Cd	n/a	LST CEN/TS 16172:2013	0.04 mg/kg
Organic Matter	n/a	LST EN 15935:2012	0.62%

The quantities of the sludge that can be used in agriculture and forestry in Lithuania are determined in the national legislation documents (LAND 20-2005) allowing to use the sludge (compost) with the rate of 33 tons per hectare at the areas for growing energy plants, nurseries, at plantations of raw wood and shrubs, forestry plantations and in greeneries. One of the main and most recent requirements are the concentrations of the heavy metals in the sewage sludge (compost), these are given in Table 7 below.

Table 7 Requirements for wastewater sludge to be used in agriculture in Lithuania (LAND 20-2005).
**Can be used every 3 years in agriculture except in planting industry of vegetables and fruits*
***Forbidden to use*

REQUEREMENS FOR SLUDGE TO BE USED IN AGRICULTURE								
mg/kg		**Zn**	**Cu**	**Cr**	**Cd**	**Pb**	**Ni**	**Hg**
CLASS	**I**	<300	<75	<140	<1.5	<140	<50	<1.0
	II*	300-2500	75-1000	140-400	1.5-20	140-400	50-300	1.0-8.0
	III**	>2500	>1000	>400	>20	>400	>300	>8.0

1.3. The Municipality of Höör / Mittskåne Vatten

Wastewater analysis

At Lyby WWTP the sampling of the inlet concentrations was done after a preliminary sand filter. In contrast, the sampling at Ormanäs WWTP was done before the sand filter, but after mechanical screening. At both plants, outlet concentrations were sampled before the treated water was diverted to the receiving water bodies.

For biological oxygen demand (BOD_7), total nitrogen (N_{tot}), ammonium nitrogen (NH_4-N) and total phosphorous outlet values (P_{tot},) composite samples were taken once a week. For the heavy metals as well as inlet values for P_{tot}, weekly flow proportional samples were collected (Table 8). All collected samples were sent to a certified laboratory (SYNLAB) for analysis. When concentrations of a compound were found to be below the detection limit, then half that concentration was used for the calculations.

Table 8 Sampling frequencies, analytical method used and detection limits for the compounds in the assessment of wastewater quality.

Parameter	Inlet	Outlet	Analytical method	Detection limit
COD_{Cr}	2 weekly/month	2 weekly/month	ISO 15705:2002	30 mg/l
BOD_7	2 daily/month	1 daily/week	SS-EN ISO 5815-1:2019	3 mg/l
Suspended solids	2 daily/month	2 daily/week	SS_EN 872, mod	5 mg/l
P_{tot}	2 weekly/month	1 daily/week	SS-EN ISO 15681-2:2018	0,005 mg/l
N_{tot}	2 daily/month	1 daily/week	SS-EN 12260:2004	0,1 mg/l
NH_4-N		1 daily/week	ISO 15923-1:2013 B	0,01 mg/l
Hg		1 weekly/month	EN ISO 15587-2, EN 1483	0,1 µg/l
Pb		1 weekly/month	ISO 17294	0,2 µg/l
Zn		1 weekly/month	ISO 17294	3 µg/l
Ni		1 weekly/month	ISO 17294	0,5 µg/l
Cr		1 weekly/month	ISO 17294	0,5 µg/l
Cu		1 weekly/month	ISO 17294	0,5 µg/l
Cd		1 weekly/month	ISO 17294	0,03 µg/l

Threshold limits for wastewater

The overall wastewater treatment process has as its goal not to exceed threshold limits set by the Swedish authorities. The relevant limits can be seen in Table 9 below. The threshold limits are adapted to the circumstances seen at each site e.g. susceptibility of the recipient will be considered when the limits are set. Therefore, the limits differ from site to site.

Table 9 Threshold limits as set by the Swedish authorities for concentrations of compounds in the effluent.

	Ormanäs WWTP		**Lyby WWTP**	
Parameter	**Concentration (mg/l)**	**Type**	**Concentration (mg/l)**	**Type**
BOD_7	10	Guiding value & monthly average	10	Guiding value & monthly average
	10	Threshold value & quarterly average	10	Threshold value & quarterly average
N_{tot}	12	Guiding value & yearly average	15	Yearly average
NH_4-N	5	Guiding value & average May-October	3	Guiding value & average June-October
			5	Yearly average
P_{tot}	0,2	Guiding value & monthly average	0,3	Guiding value & monthly average
			0,25	Guiding value July-September
	0,3	Threshold value & quarterly average	0,3	Threshold value & quarterly average

Sludge analysis

For the sludge, a sample was collected every week and frozen. The frozen samples were then sent for joint analysis every second month at Lyby WWTP and every third month at Ormanäs WWTP. All samples were sent to a certified laboratory (SYNLAB) to determine percentage of dry matter (DM) and concentrations of nutrients and metals. In Table 10 the analytical method, threshold limit and detection limit for sludge quality parameters are presented.

Table 10 Analytical method and associated detection limit in the assessment of sludge quality.

Parameter	**Threshold limit**	**Analytical method**	**Detection limit**
Dry matter (%)	-	SS-EN 12880-1:2000	0,1 %
N_{tot}	-	SS-EN 16169:2012	1 g/kg DM
P_{tot}	-	EN16174,EN16171/ISO11885	0,01 g/kg DM
Hg	2,5 mg/kg DM	EN 16174, ISO 16772-1	0,025 mg/kg DM
Pb	100 mg/kg DM	EN16174,EN16171/ISO11885	2 mg/kg DM
Zn	800 mg/kg DM	EN16174,EN16171/ISO11885	7,5 mg/kg DM
Ni	50 mg/kg DM	EN16174,EN16171/ISO11885	1 mg/kg DM
Cr	100 mg/kg DM	EN16174,EN16171/ISO11885	1 mg/kg DM

Cu	600 mg/kg DM	EN16174,EN16171/ISO11885	5 mg/kg DM
Cd	2 mg/kg DM	EN16174,EN16171/ISO11885	0,2 mg/kg DM

1.4. Goleniów Water and Sewage Company

Wastewater analysis

At the Goleniów WWTP, flow-proportional sampling of the daily average of raw and treated wastewater takes place twice a month using an automatic sampler in accordance with the PN - ISO 5667-10 1997 (A). Samples are analysed in an accredited laboratory. According to the water permit the parameters COD, BOD5, Ptot, Ntot are analysed together with total suspended solids. As part of the internal quality control, the effluent is tested daily for total nitrogen and total phosphorus. The methods of determining the main parameters of waste water quality are presented in Table 11 below.

Table 11 Applied analytical method and compound detection limits in wastewater quality assessment.

Parameter	Threshold value	Analytical method	Detection limit
COD	50000 mg/l O_2	PN-ISO 15705:2005 (A)	5 mg/l O_2
BOD_5	6000 mg/l O_2	PN-EN 1899–1:2002 w wył.p. 7.2; kj-i-5.4-1 wersja 05 z dnia 20.01.2015 r. PN – EN ISO 5815-1:2019-12	0,50 mg/l O_2
P_{tot}	100 mg/l	PN-EN-ISO 15681-2:2019-02	0,10 mg/l
N_{tot}	3000 mg/l	PN-EN 12260:2004 (A), (NR)	0,5 mg/l
Total suspension	5000 mg/l	PN-EN 872:2007 +Ap 1:2007	2,0 mg/l

Threshold limits for wastewater

Threshold values for wastewater quality parameters at Goleniów WWTP are seen in Table 12 below.

Table 12 Threshold values for wastewater quality parameters. MAC – Maximum allowed concentration.

Parameter	Threshold value / MAC (mg/l)	Type
COD	125	Daily average
BOD_5	15	Daily average
N_{tot}	15	Yearly average
P_{tot}	2	Yearly average
Total suspension	35	Daily average

Sludge analysis

National legislation on the treatment and final disposal of municipal sewage sludge, which constitutes waste, is set out in the Act on Waste of 14 December 2012 (Journal of Laws of 2012, No. 101, item 1571). U. 2020, pos.797), and the Regulation of the Minister of Environment of 6 February 2015 on Municipal Sewage Sludge (OJ Cf. U. 2015.pos. 257). The aforementioned legal acts define the conditions, frequency and types of sludge and soil which should be performed before the application of sludge, as well as the obligations of the sludge producer and the landowner. It is also possible to use stabilized municipal sewage sludge for the production of fertilizer or plant growth promoter, which is regulated by Announcement of the Marshal of the Sejm of the Republic of Poland of June 7, 2018 on the publication of the consolidated text of the Act on fertilizers and fertilization (Journal of Laws of 2018, item 1259) and the Ordinance of the Minister of Agriculture and Rural Development of June 18, 2008 on the implementation of certain provisions of the Act on fertilizers and fertilization (Journal of Laws 2008 No. 129, item 76). These Acts define the conditions for the placing on the market of products made from municipal sewage sludge and indicate the way to obtain an authorisation to place a product on the market by obtaining an opinion from the relevant research institutes.

Sewage sludge testing must be performed in certified laboratories and include:

- pH reaction
- dry matter content
- organic matter content in dry matter of sludge
- Total nitrogen content, including ammoniacal nitrogen
- Total phosphorus content Calcium and mugnesium content
- Heavy metal content in the dry matter of the sludge – se Table 13 below.
- Salmonella count - Intestinal parasite egg count Ascaris sp. Trichuris sp. and Toxocara sp.

Table 13 Maximum content of heavy metals in municipal sewage sludge.

Metals	Threshold limit for heavy metal content (mg/kg of dry matter of sludge) when using municipal sewage sludge:		
	in agriculture and for the reclamation of land for agricultural purposes	for the reclamation of land for non-agricultural purposes	when adapting land to specific needs resulting from waste management plans, spatial development plans or decisions on land development conditions, to growing plants intended for compost production, to growing plants not intended for food or feed production
Cadmium (Cd)	20	25	50
Copper (Cu)	1000	1200	2000
Nickel (Ni)	300	400	500
Lead (Pb)	750	1000	1500
Zinc (Zn)	2500	3500	5000
Mercury (Hg)	16	20	25

Chromium (Cr)	500	1000	2500

The presence of Salmonella live eggs from intestinal parasites prevents the use of sludge in agriculture and for land reclamation for agricultural purposes. The total number of live eggs of the intestinal parasite Ascaris sp, Irichuris sp., Toxocara sp. Allowed in 1 kg of dry matter of sludge to be used for testing:

- in agriculture and for land reclamation for agricultural purposes is 0
- for recultivation of land, for adaptation of land to specific needs resulting from waste management plans, spatial development plans or decisions on land development conditions, for growing plants intended for compost production, for growing plants not intended for consumption and for fodder production is not more than 300

Sludge shall not be applied to soils at risk of heavy metal contamination. Before applying the sludge, it is necessary to test the soil in order to assess its initial condition and further monitoring. The maximum dose of sewage sludge that can be used in agriculture and for recultivation of land for agricultural and other purposes is shown in Table 14. Moreover, the dose of sludge should be determined in such a way that its application on a given land will not result in exceeding permissible levels of heavy metals according to Table 15.

Table 14 Permissible concentrations of heavy metals in soil when sewage sludge is used in relation to the agronomic category of soil. S.m is dry matter of sludge.

<table>
<tr><th>Objective</th><th>Use throughout the year</th><th>Use 1x for 2 years</th><th>Use 1x for 3 years</th></tr>
<tr><td>Agriculture</td><td rowspan="2">3 Mg s.m./ha</td><td rowspan="2">6 Mg s.m./ha</td><td rowspan="2">9 Mg s.m./ha</td></tr>
<tr><td>Reclamation of land for agricultural purposes</td></tr>
<tr><td>Reclamation of land for non - agricultural purposes</td><td rowspan="4">15 Mg s.m./ha</td><td rowspan="4">30 Mg s.m./ha</td><td rowspan="4">45 Mg s.m./ha</td></tr>
<tr><td>Adaptation of land to specific needs resulting from waste management plans, Land use plans,</td></tr>
<tr><td>Growing of plants intended for compost production,</td></tr>
<tr><td>Growing of plants not intended for use for fodder production.</td></tr>
</table>

Table 15 Permissible concentrations of soil heavy metals when sewage sludge is applied - depending on the agronomic category of soil.

Metal	The limit value for the amount of heavy metals (mg/kg of dry matter of the soil) in the different soil types		
	light	*medium*	*heavy*
Cadmium (Cd)	1	2	3
Copper (Cu)	25	50	75
Nickel (Ni)	20	35	50
Lead (Pb)	40	60	80
Zinc (Zn)	80	120	180
Mercury (Hg)	0,8	1,2	1,5
Chromium (Cr)	50	75	100

The sludge produced at the Goleniów WWTP is subject to the recovery process R3 composting. There are no legal regulations that impose an obligation to test batches of sludge submitted to the composting process, however, in order to maintain the high quality of the product, the sludge submitted to the composting process is tested by an accredited laboratory for percentage of dry mass, concentration of nutrients, heavy metals and microbiological aspects in accordance with Table 16 below.

Table 16 Parameters, limit values, analytical method and associated detection limit in the assessment of the sludge quality in the Goleniów WWTP.

Parameter	**Analytical method**	**Detection limit**
Dry matter (residue) (% sm)	PN-EN 15934:2013-02 z wył.p.7,method B (A)	(0,1 – 99,5%) %
Organic substance (% sm)	PN-EN 15935:2013-02	(0,1-99,5) %
Total nitrogen content (% sm)	PN-EN 16168:2012 (A), (NR)	(1,00-20,0)%
Phosphorus (% sm)	PN-EN 16171:2017-02 (A)	(5-100 000) mg/kg
Hg mg/kg sm	KJ-I-5.4-36 (A), (NR)	(0,005-10,00) mg/kg
Ca (% sm)	PN-EN 16171:2017-02 (A)	(30,0-500 000) mg/kg
Cd mg/kg sm	PN-EN 16171:2017-02 (A)	(0,25-1 000) mg/kg
Cr mg/kg sm	PN-EN 16171:2017-02 (A)	(2,5 – 10 000) mg/kg
Cu mg/kg sm	PN-EN 16171:2017-02 (A)	(5,00 – 10 000) mg/kg

Fe mg/kg sm	PN-EN 16171:2017-02 (A)	(5,00-10 000) mg/kg s.m.
K (% sm)	PN-EN 16171:2017-02 (A)	(100 – 75 000) mg/kg
Mg (% sm)	PN-EN 16171:2017-02 (A)	(10,0 – 200 000) mg/kg
Ni mg/kg sm	PN-EN 16171:2017-02 (A)	(2,5 -10 000) mg/kg
Pb mg/kg sm	PN-EN 16171:2017-02 (A)	(2,5-10 000) mg/kg
Zn mg/kg sm	PN-EN 16171:2017-02 (A)	(2,5 -10 000) mg/kg
Presence Salmonella sp. (in the test mass or volume) spp. 25g, 100g	PN EN ISO 6579-1:2017-04 (A)	Detected/ not detected
Number Ascaris sp., Trichuris sp., Toxocara sp. (liczba/kg sm) in100 g	KJ-I-5.4-59M (A)	(0) number/kilogram dry matter

2. WASTEWATER QUALITY ASSESSMENT AT WWTP OF PROJECT PARTNERS

2.1. Bornholms Energy & Supply

Biological Oxygen Demand (BOD) & Chemical Oxygen Demand (COD)

The influent levels of BOD_5 to Rønne WWTP were observed to be on average 348 mg/l, and average COD 909 mg/l. The outlet concentrations were of BOD_5 were observed to be on average 2,7 mg/l, and average COD 22 mg/l (se Figure 1).

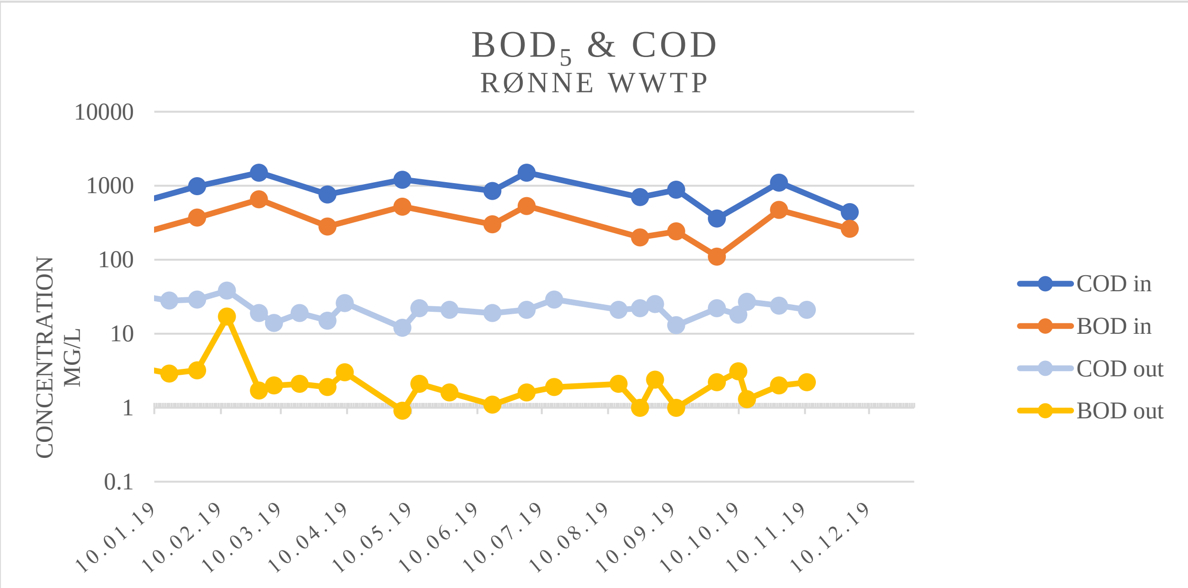

Figure 1 Inlet and outlet concentretions of BOD_7 and COD_{Cr} at Rönne WWTP (OBS! logarithmic scale).

The increased outlet values during mid-February were connected to high flows.

The average ratio between COD and BOD_5 (COD/BOD_5) was 2,7 and 9,2 in the inlet respectively the outlet – thus illustrating effective removal of BOD_5 in contrast to COD, with a larger fraction of organic matter slowly degradable biologically. In average the reduction of BOD_5 was 99,1% and COD 97,4% throughout 2019.

The limiting yearly average concentration for the outlet from Rønne WWTP was not exceeded for neither COD nor BOD_5 (75 mg/l respectively 15 mg/l).

Total suspended solids (TSS)

The concentration of total suspended solids was not analysed at Rønne WWTP, this since it is not required by the authorities.

Total nitrogen & phosphorous

The inlet concentrations of total nitrogen to Rønne WWTP were observed to be on average 50,8 mg/l, and for phosphorous the inlet concentrations showed to be on average 8 mg/l. The outlet concentrations of total nitrogen were observed to be on average 4 mg/l, and 0,27 mg/l for phosphorous (Figure 2).

The inlet concentrations of total nitrogen and total phosphorous show to follow the same general pattern.

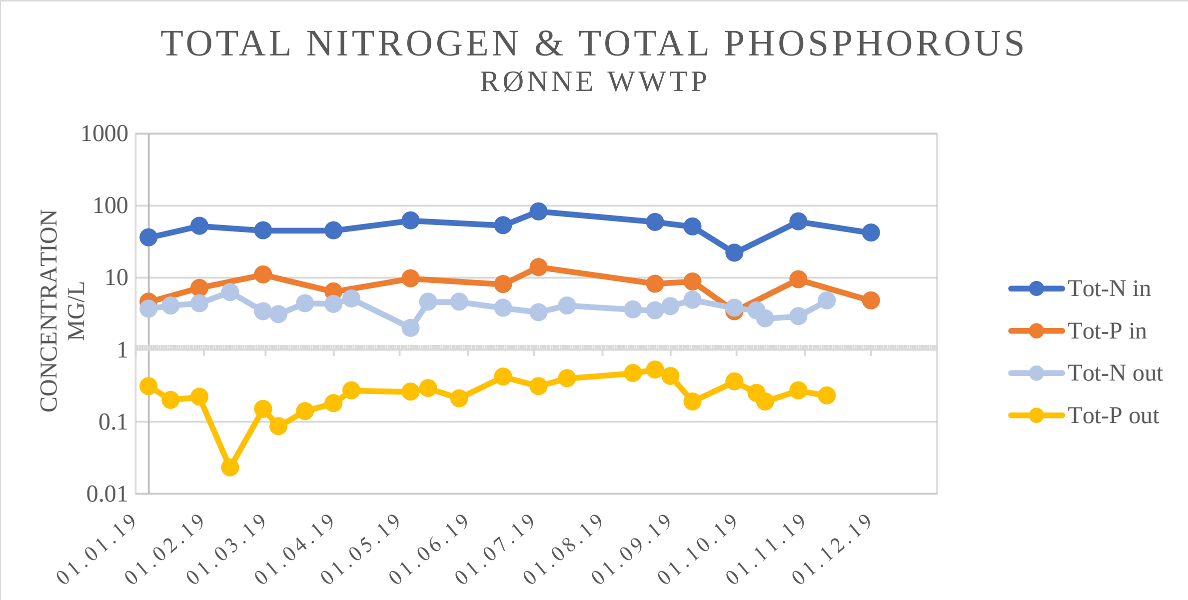

Figure 2 Inlet and outlet concentretions of total nitrogen and total phosphorous at Rönne WWTP (OBS! logarithmic scale).

The limiting yearly average concentration for the outlet from Rønne WWTP was not exceeded for neither N_{tot} nor P_{tot} (8 mg/l respectively 1,5 mg/l).

Inorganic nitrogen & phosphorous

Measuring the concentration of inorganic nitrogen and phosphorous is not demanded by the Danish authorities and was therefore not a part of the official analysis programme at Rønne WWTP. However, internal analysis of the substances was conducted as well as on-line monitoring. Internal analysis showed that the ammonia concentration in the outlet from Rønne WWTP was generally around 0,4 mg/l and nitrate concentration about 3 mg/l.

Organic micropollutants

For the STEP project, micropollutants and PFAS were analysed at three occasions in the inlet and outlet from Rønne WWTP.

The analysed micropollutants were:

- **LAS:** Linear Alkylbenzene Sulphonates, which are the most extensive used anionic detergents in cleansing agents. Non-anaerobic degradable substances. Affect marine organisms. Despite the high separation efficiency in sewage treatment plants, LAS outlet concentrations are generally in the range 0,02 – 0,9 mg/l.
- **PAH:** Polycyclic aromatic hydrocarbons, of interest due to their potential toxic and carcinogenic properties. Due to their low water solubility and their high affinity for organic matter, PAHs are easily concentrated in sewage sludge**.**

- **NPE:** Group of nonionic detergents which are present in many laundry and cleaning agents. Important group of substances in the discussion regarding if the agricultural sector could continue as a receiver of sludge.
- **DEHP:** Diethylhexylphthalat, which belongs to a group of phthalate esters which is used in large amounts as softener or plasticizer in Polyvinyl Chloride (PVC).
- **PFAS:** Per- and polyfluoroalkyl substances, which are a group of man-made chemicals. These chemicals are very persistent in the environment and in the human body and there is evidence that exposure to PFAS can lead to adverse human health effects.

The outlet concentrations of LAS, PAH and NPE were observed to be below detection limit. Concentrations of organic micropollutants at Rønne WWTP are seen in Figure 3below.

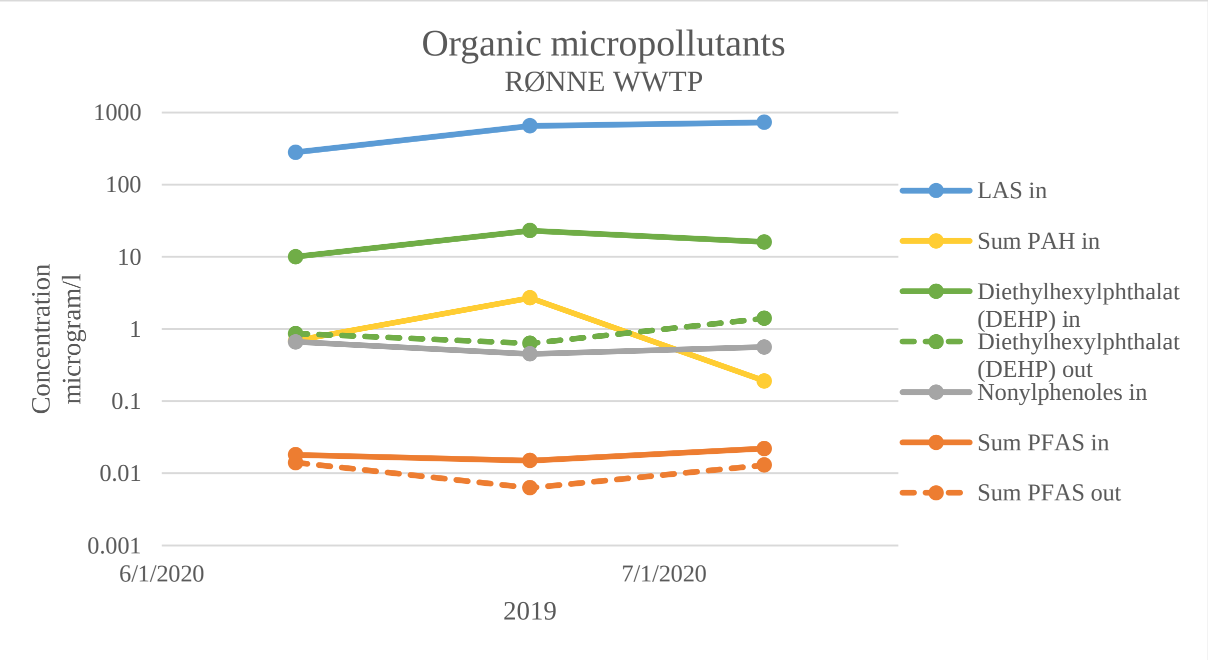

Figure 3 Inlet and outlet concentrations of organic micropollutants, Rønne WWTP 2020 (OBS! Logarithmic scale). LAS out and PAH out, are not shown in the figure because most of the values was below the detection limit

Further analysis and discussion on organic micropollutants are seen in *Study of distribution of PAE in water and sludge.*

Heavy metals

Heavy metals were not analysed in the wastewater (in/out) from Rønne WWTP, only in the sludge.

2.2. Klaipeda University

Biological Oxygen Demand (BOD) & Chemical Oxygen Demand (COD)

At Klaipeda WWTP the inlet concentrations of BOD_7 and COD were fluctuating throughout the year (see Figure 4). The highest inlet BOD_7 concentration of 667.8 mg O_2/ l was observed in June 2019. The lowest outlet concentration of BOD_7 was observed in July 2019, it reached 3.16 mg O_2/l.

The highest inlet COD concentration of 1518.7 mg O_2/l was observed in November 2019. The lowest outlet concentration of COD was 42 mg O_2/l in July 2019.

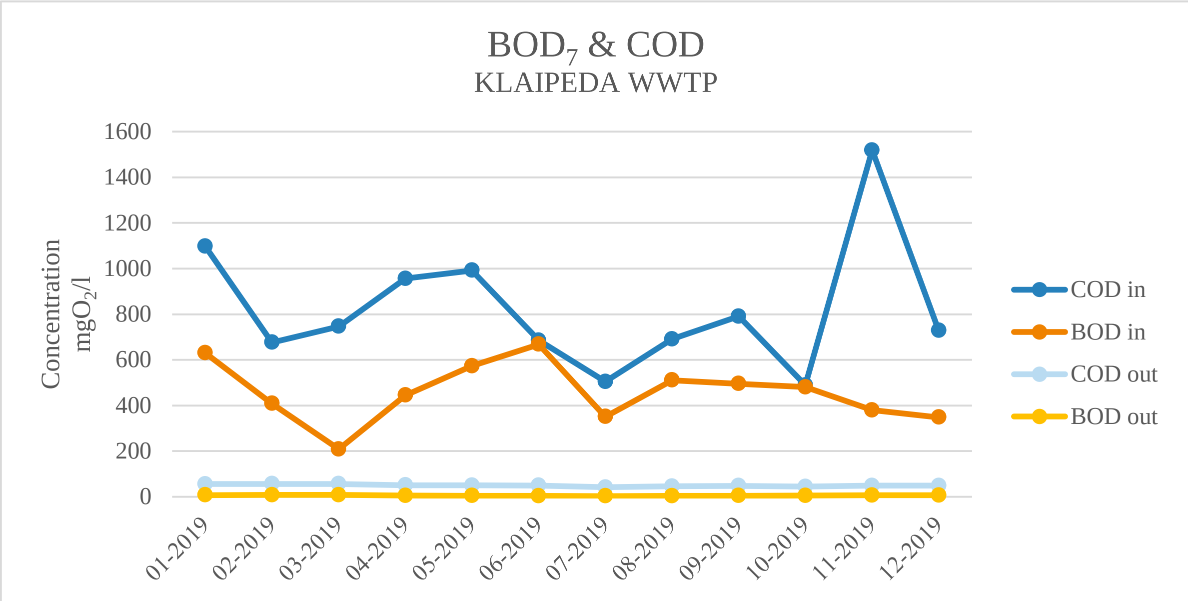

Figure 4 Inlet and outlet concentretions of BOD_7 and COD_{Cr} at Klaipeda WWTP.

The high COD inlet concentrations show that there is a high chemical wastewater pollution at the Klaipeda WWTP. However, due to the efficiency of the complex mechanical and biological wastewater treatment, the outlet concentrations of BOD and COD did not exceed threshold limits.

Inlet concentrations of COD were increased in October 2019 due to the acceptance of untreated wastewater from the cardboard company AB Grigeo Klaipeda. The average COD concentration in the wastewater from this company was approximately 7500 mgO_2/l. The impact of such pollution on the BOD_7 concentrations was managed in the biological wastewater treatment.

The dynamic of the monthly BOD_7 concentrations during 2014-2018 is presented in Figure 5 and demonstrates a tendency of higher BOD_7 outlet concentrations during the colder periods. The corresponding dynamic for COD shows a more stable trend and implies that the COD treatment is less affected by temperature changes.

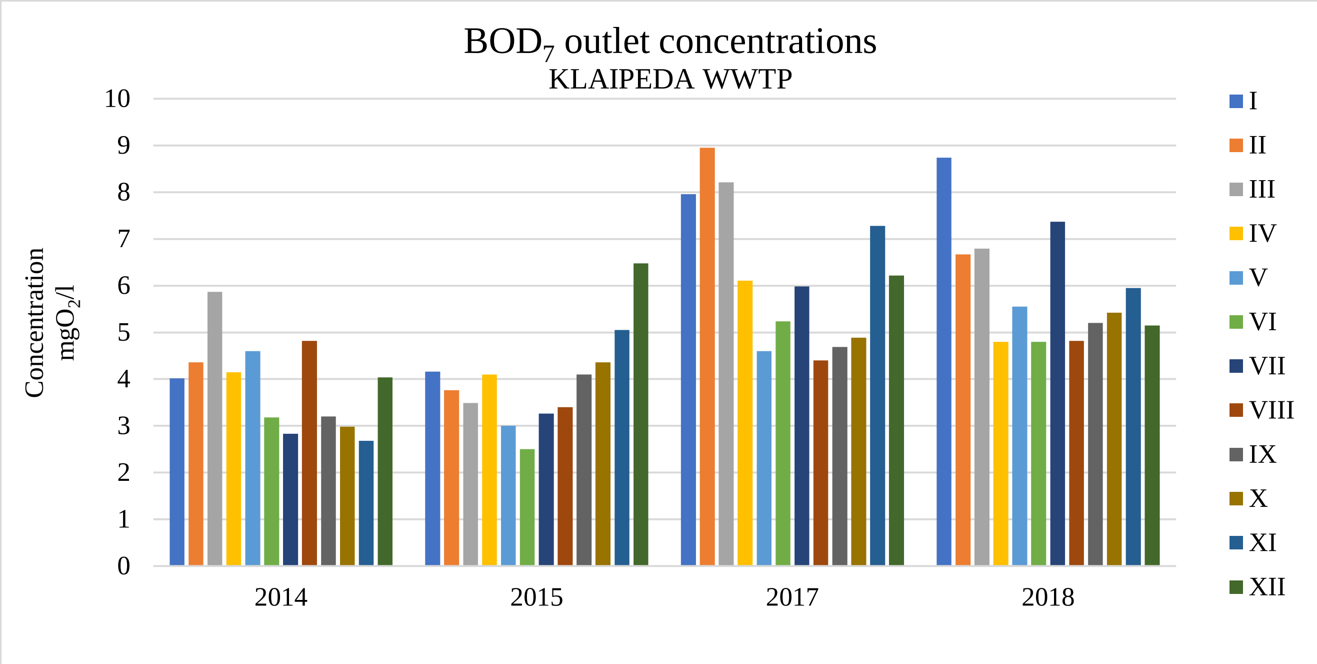

Figure 5 Montly BOD_7 concentrations 2014-2018.

Total suspended solids (TSS)

The concentration of total suspended solids was not analysed at Klaipeda WWTP.

Total nitrogen & phosphorous

The average inlet concentration of total phosphorus to Klaipeda WWTP was 9.56 mg/l. The outlet concentration of total phosphor was max 0.51 mg/l, and the threshold limit of an annual average of 0,51 mg/l was not exceeded. Concentrations are seen in Figure 6 below.

In 2019 the average inlet concentration of total nitrogen in was 108.8 mg/l. The maximum outlet concentration of total nitrogen reached 10.8 mg/l, and the threshold limit of an annual average of 10 mg/l was not exceeded.

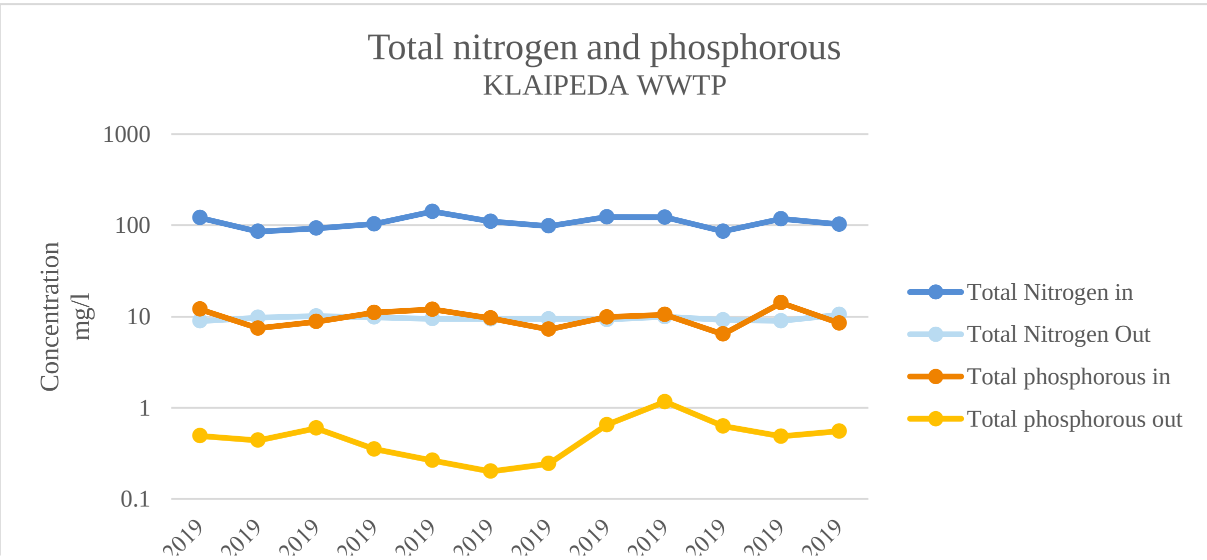

Figure 6 Inlet and outlet concentretions of total nitrogen and total phosphorous at Klaipeda WWTP (OBS! logarithmic scale).

The dynamic of the monthly average concentrations of total phosphorous in the outlet from Klaipeda WWTP 2014-2018 shows how the treatment is more efficient during the summer months. This stands in contrast to the dynamic of the monthly average concentration of total nitrogen (2014-2018) which has shown to be more stable throughout the years. Despite the trend differences the results of the biological treatment at Klaipeda WWTP regarding nutrition show that both the anaerobic and the aerobic part of the treatment process is working well.

Nowadays, Klaipeda wastewater treatment plant reliably treats the city's domestic and industrial wastewater. In the current urban wastewater treatment plant, wastewater is treated using mechanical and biological methods, and the effluent treatment effect over the last 10 years is 98-99% in terms of BOD_7 concentration, 85-92% in terms of total nitrogen and 93-97% in terms of total phosphorus.

Organic micropollutants

Analysis and discussion on organic micropollutants are seen in *Study of distribution of PAE in water and sludge.*

Heavy metals

At Klaipeda WWTP the outlet concentrations of mercury (Hg), lead (Pb), cadmium (Cd), chromium (Cr), zinc (Zn), copper (Cu) and Nickle (Ni) were measured. Inlet concentrations were not analysed.

Among all the analysed metals the lowest concentrations were found belonging to mercury. It reached a concentration of 0.04 µg/l in April, May, July, August and October 2019, and for remaining months a bit higher with a maximum of 0.12 µg/l. The concentrations of cadmium and chromium were also found to be low – generally below the detection limit of 0.2 µg/l (Cd) respectively 1.0 µg/l (Cr). Twice the chromium concentrations were observed above detection limit. Concentrations of chromium, cadmium and mercury are found in figure Figure 7 below.

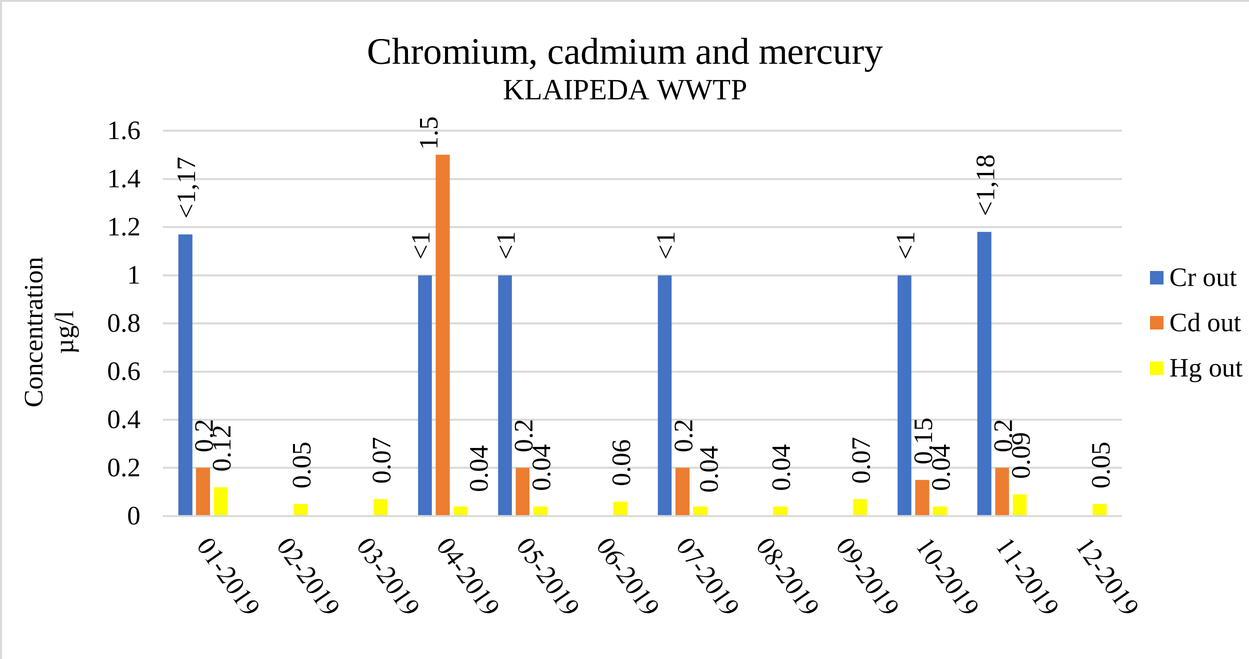

Figure 7 Outlet concentrations of chromium, cadmium and mercury at Klaipeda WWTP during 2019.

The highest outlet concentrations during 2019 were observed belonging to zinc which causes big issues for the sewage treatment at Klaipeda WWTP, see Figure 8. The highest zinc outlet concentration, of 0.64 mg/l, was observed in July 2019. The lowest outlet concentration of zinc was observed in June 2019 and reached 0.05 mg/l.

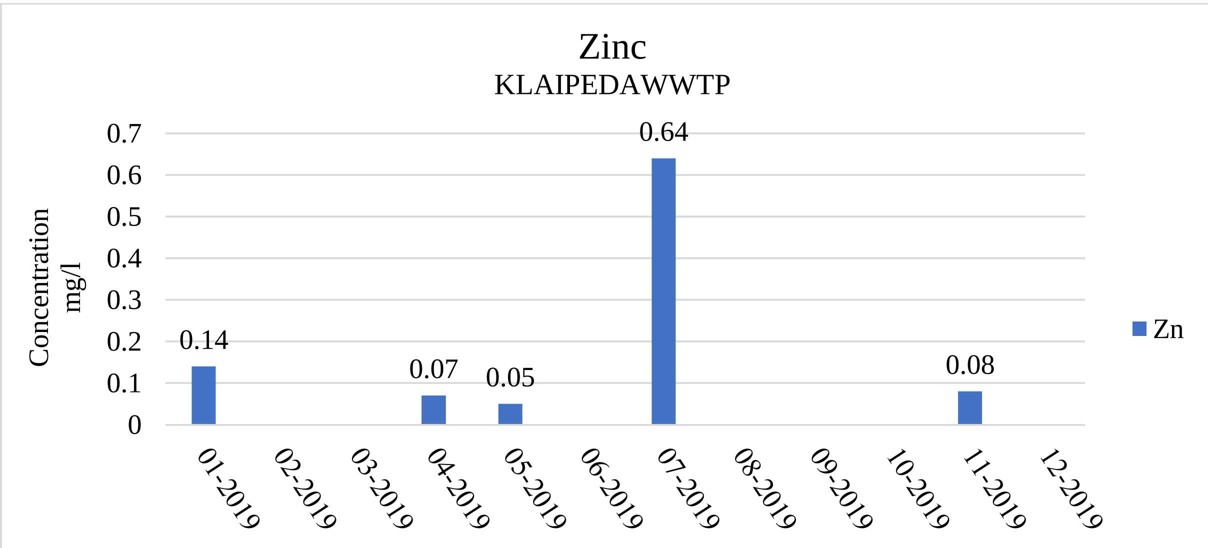

Figure 8 Outlet concentration of zinc at Klaipeda WWTP during 2019.

The remaining analysed heavy metals were copper, nickel and lead, se Figure 9. The highest copper outlet concentration of 48.8 µg/l was observed in January 2019. The lowest concentrations of copper in the outlet were observed in May and November 2019 and reached 3 µg/l. The highest nickel outlet concentrations of 4 µg/l were observed in January, May, July and November 2019. The lowest outlet concentrations of nickel were observed in September 2019 and reached 2.5 µg/l. Inlet concentration data was not provided. Among these three heavy metals the lowest concentration was observed for lead. The mean concentration ranged below 2 µg/l.

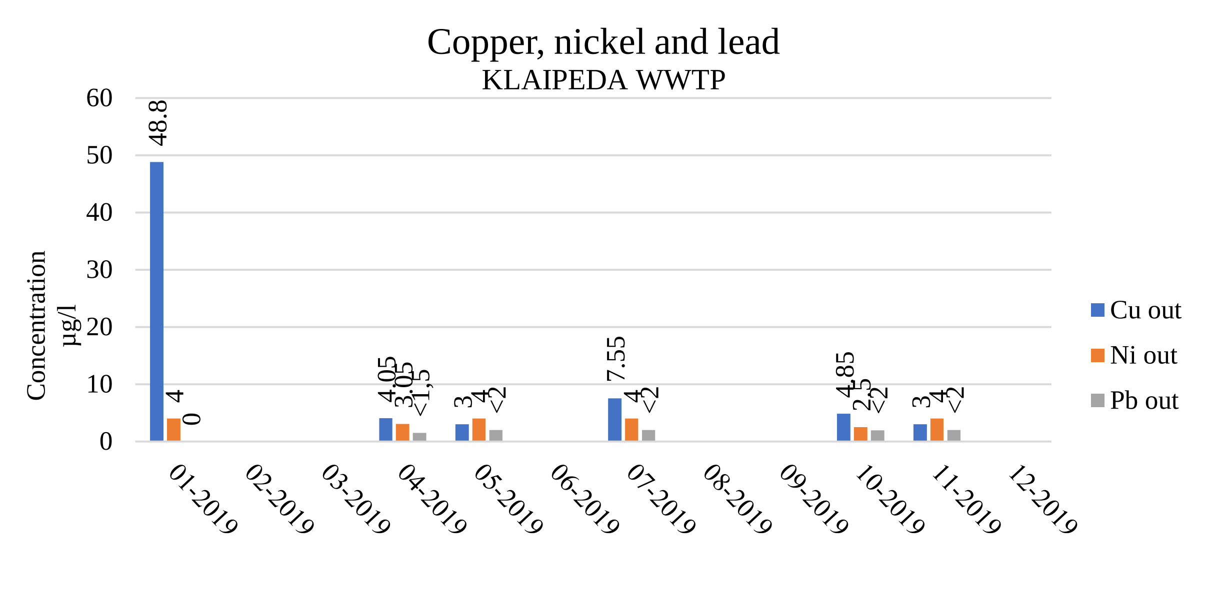

Figure 9 Outlet concentrations of copper, nickel and lead at Klaipeda WWTP during 2019.

The heavy metal concentrations remaining in the wastewater after treatment were small, and about 70% of the metals remained in the sludge.

The pH value at the Klaipeda WWTP was quite stable during 2019. The highest inlet pH was observed in February and March 2019 and reached 7.9 (see Figure 10). The lowest inlet pH was 7.7. The lowest pH in the outlet was detected in January and February 2019 and was 7.5. The outlet level of pH was observed as highest in September 2019 at a level of 7.9.

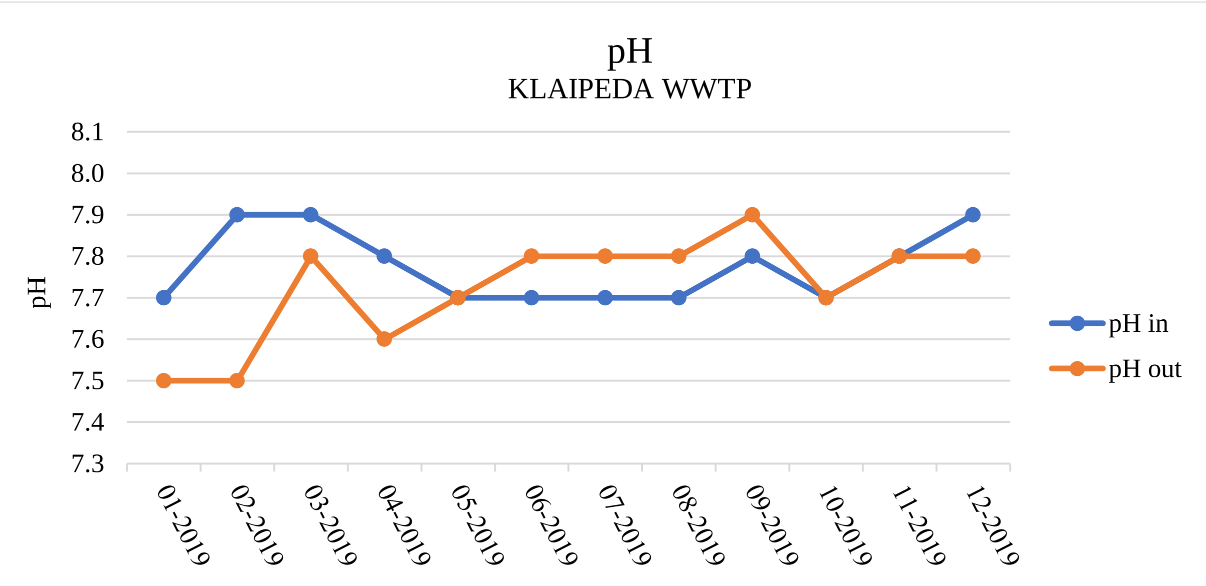

Figure 10 Observed pH values at Klaipeda WWTP during 2019.

Oil products, grease and detergents

The average concentrations of oil products in the inlet of Klaipeda WWTP was during 2019 maximum 290 mg/l, minimum 0.47 mg/l, and average 31.80 mg/l and corresponding concentrations in the outlet were maximum 0,11 mg/l, minimum 0 mg/l and average 0.037 mg/l (see Figure 11).

For grease, average concentrations in the inlet of Klaipeda WWTP was during 2019 maximum 89 mg/l, minimum 5 mg/l, and average 39.5 mg/l and corresponding concentrations in the outlet were maximum 4.8 mg/l, minimum 0 mg/l and average 0.16 mg/l (see Figure 11).

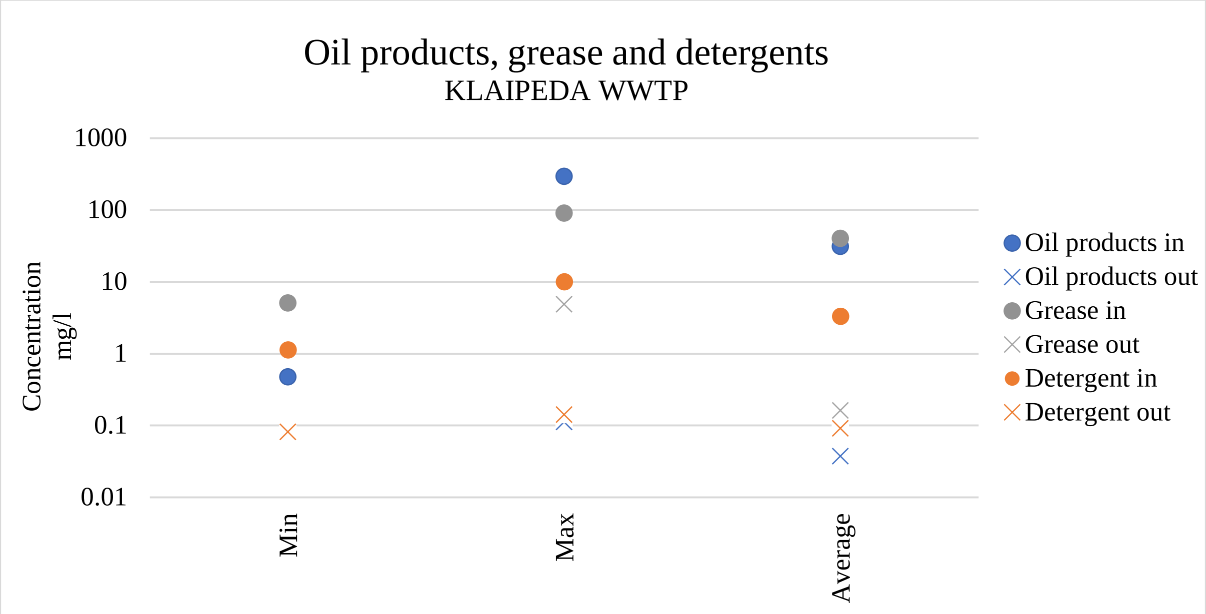

Figure 11 Concentrations of oil products, grease and detergents at Klaiped WWTP during 2019.

Finally, for detergents average concentrations in the inlet of Klaipeda WWTP was during 2019 maximum 10 mg/l, minimum 1.12 mg/l, and average 3.31 mg/l and corresponding concentrations in the outlet were maximum 0.14 mg/l, minimum 0.08 mg/l and average 0.09 mg/l (see Figure 11).

The results show that the mechanical treatment steps at the Klaipeda WWTP are functioning successfully in relation to reduction of the above-mentioned pollutants.

2.3. THE MUNICIPALITY OF HÖÖR / MITTSKÅNE VATTEN

Biological Oxygen Demand (BOD) & Chemical Oxygen Demand (COD)

At Lyby WWTP the influent concentrations of BOD_7 were observed to be on average 241 mg/l. Outlet concentrations of BOD_7 were all found to be below the lowest detectable limit of 3 mg/l (see Figure 12).

For COD_{Cr} the inlet concentrations, to Lyby WWTP, were found to be relatively low during the beginning of the year, with an average concentration of about 200 mg/l up until week 15. For the remainder of the year the average inlet concentration was higher, 585 mg/l. Despite the difference in average inlet concentrations the outlet concentration was at no point observed to be above the lowest detectable limit of 30 mg/l (see Figure 12).

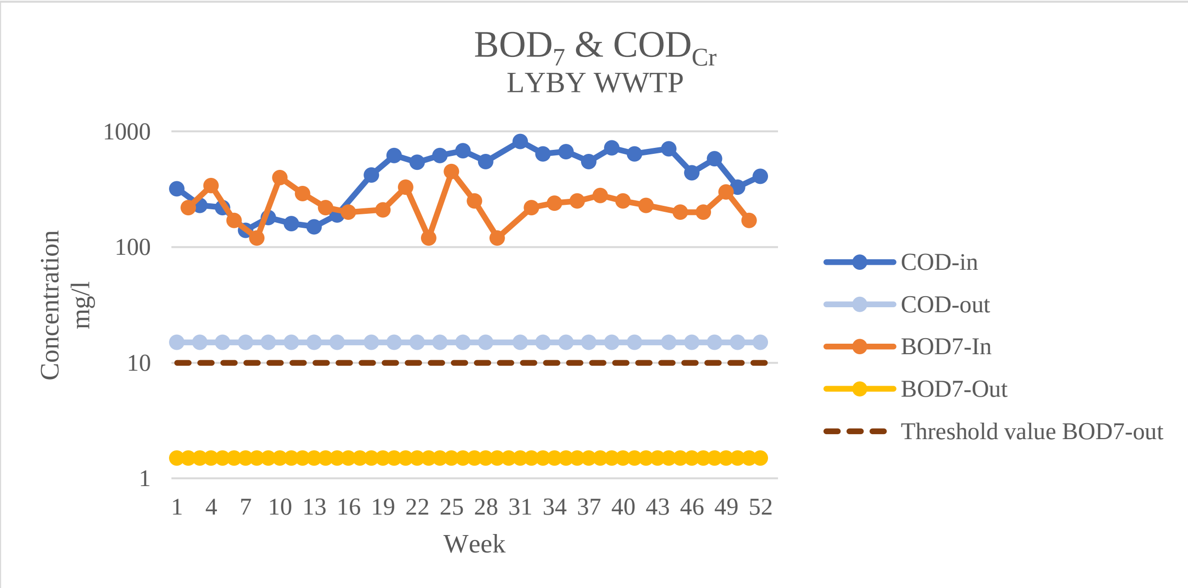

Figure 12 Inlet and outlet concentretions of BOD_7 and COD_{Cr} at Lyby WWTP (OBS! logarithmic scale). Outlet levels for BOD_7 were not noted to exceed the detection limit of 3mg/l and are therefore presented as 1,5mg/l which is half the detection limit. Outlet levels for COD_{Cr} were not noted to exceed the detection limit of 30mg/l and are therefore presented as 15mg/l which is half the detection limit.

The difference seen for average incoming concentrations of COD_{Cr} could be due to dilution by excess water during the wetter months. Data from the Swedish Meteorological and Hydrological Institute (SMHI) shows how the precipitation during February, March, September and October 2019 was normal or above normal whilst January, April – August and November – December had precipitation between 5-75% of the monthly normal precipitation. This corresponds to the dilution of COD_{Cr} during February and March and that no effect is seen during September and October may be because precipitation during these months probably would be soaking the dry soils.

For both BOD_7 and COD_{Cr} the treatment efficiency is high and gives sufficient treatment before the effluent is discharged into the recipient.

For Ormanäs WWTP the average inlet and outlet concentrations of BOD_7 were found to be 114 mg/l and 2,6 mg/l respectively. Peak inlet concentration occurred during week 32 and 41 with observed levels of 190 and 220 mg/l (Figure 13), and generally the inlet concentrations were seen to be quite fluctuating. This was due to an overload of the filters. However, the corresponding outlet concentrations were not registered above the detection limit. Instead, a peak in outlet concentration was determined to 23 mg/l during week 31. The lowest measured treatment efficiency stems from this period at 94%.

The COD_{Cr} inlet concentrations were, as the BOD_7 inlet concentrations, found to be fluctuating. The maximum inlet concentrations were recorded during the first week of the year and week 42, with levels of 400 and 410 mg/l respectively (Figure 13). Week 18, inlet concentrations were observed to be at a minimum of 87 mg/l. This week outlet concentrations were also relatively high (44 mg/l) and treatment efficiency at its lowest (49%). This was since the filters in the final treatment step was not functioning properly. Seen was also a higher COD_{Cr} outlet concentration during week 11.

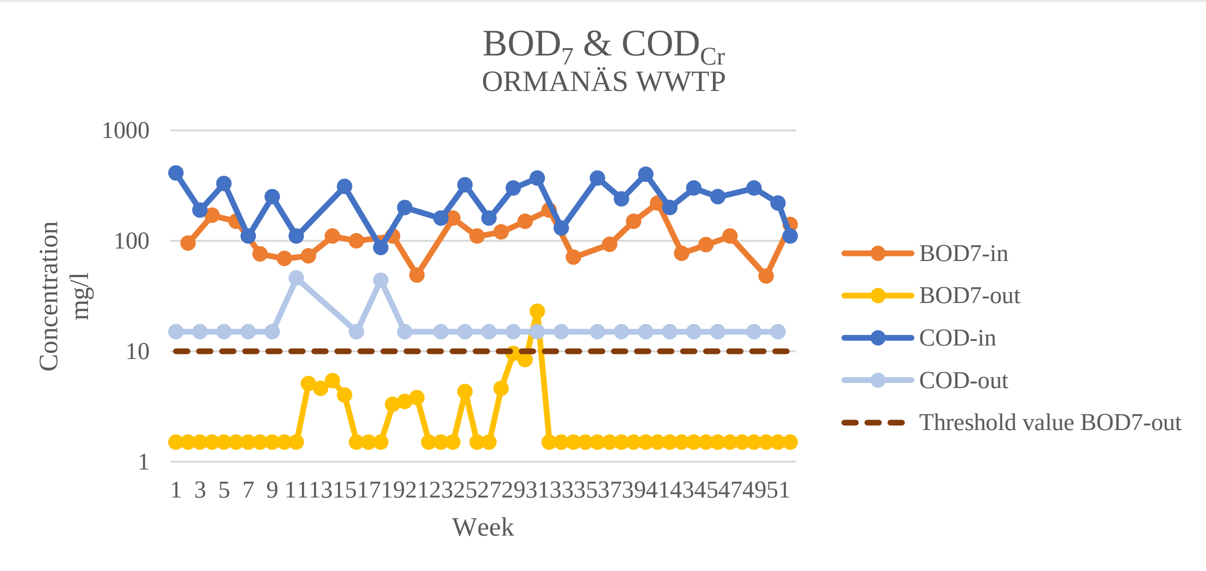

Figure 13 Inlet and outlet concentretions of BOD_7 and COD_{Cr} at Ormanäs WWTP (OBS! logarithmic scale). If outlet levels for BOD_7 were noted not to exceed the detection limit of 3mg/l they are presented as 1,5mg/l which is half the detection limit. If outlet levels for COD_{Cr} were noted not to exceed the detection limit of 30mg/l they are presented as 15mg/l which is half the detection limit.

Seen in the results is that higher inlet concentrations of BOD_7 were observed at Lyby WWTP compared to Ormanäs WWTP. The main reason for this is that Lyby WWTP receives wastewater from a slaughterhouse which increases the BOD_7 concentrations substantially.

Ormanäs WWTP is known to be highly affected by excess water and the efficiency of the aerators at Ormanäs WWTP is not optimal. The system shows very little resilience towards excess water and this could be one reason for the highly fluctuating values – even small rainfall events may have a large effect at the WWTP. This may also be a reason for concentrations at Ormanäs WWTP being in general lower (more diluted by excess water) than the concentrations seen at Lyby WWTP during the dry period but at the same time higher than the concentrations seen during the wet period.

During the summer months there were problems with large amounts of sludge at Ormanäs WWTP. Manual removal of sludge was needed as well as extra rinsing of the filters. In addition, the flows to the treatment plant during March were very high which led to a hydraulic overload which in turn caused sludge from the biological treatment step to block the filters. The filters were rinsed on several extra occasions however despite this, particles where washed out with the outflow. An increased amount of sludge in the outflow causes high concentrations of BOD7, suspended solids, COD_{Cr}, phosphorous and nitrogen.

Further on, wastewater which is diluted with large amounts of excess water is colder than the non-diluted wastewater which leads to less efficient treatment.

<u>Inorganic nitrogen & total nitrogen</u>

The inlet concentrations of total nitrogen to Lyby WWTP were found to be in the interval of 30 – 60 mg/l except for one occasion during week 37 when a concentration of 67 mg/l was noted (Figure 14). Outlet concentrations were below the threshold limit of 15 mg/l except for week 3 when precisely that concentration was recorded. Treatment efficiencies were on average 84%.

Ammonium inlet concentrations at Lyby WWTP were not measured during 2019. The outlet levels were all below 0,5 mg/l.

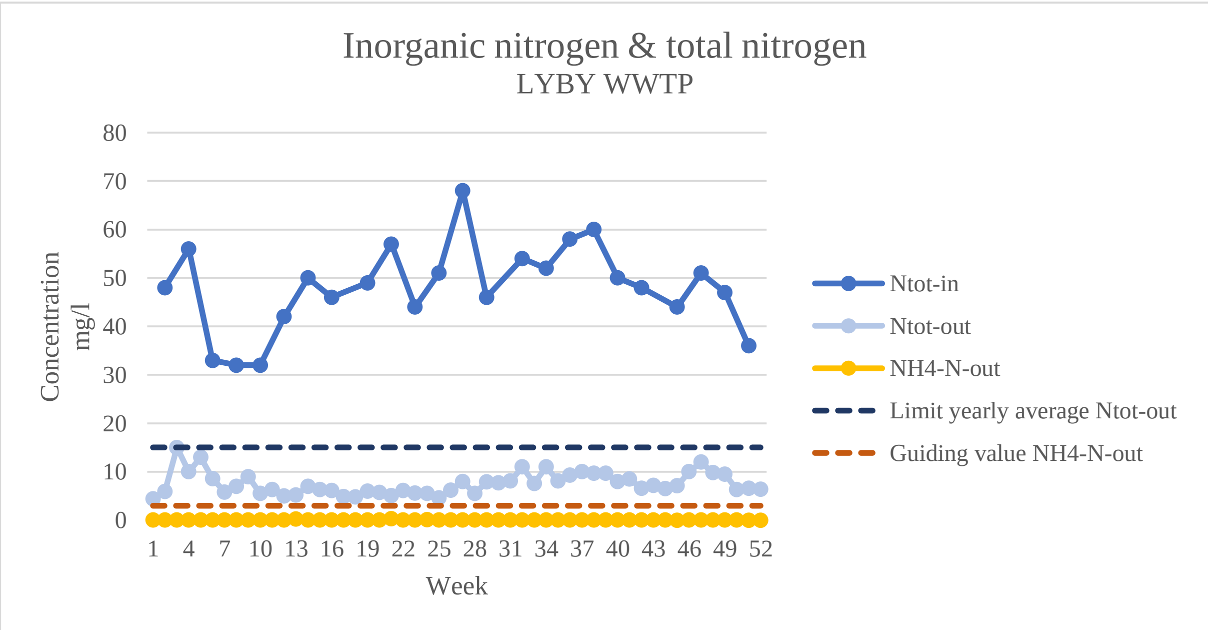

Figure 14 Inlet and outlet concentretions of N_{tot} and outlet concentrations of NH_4-N at Lyby WWTP, the limiting yearly average for N_{tot} outlet concentrations and the guiding value for NH_4-N outlet concentrations.

For Ormanäs WWTP the inlet concentrations of total nitrogen were found to be roughly 30 mg/l. A peak occurred during week 39 when a level of 62 mg/l was noted (Figure 15). However, this increase did not seem to influence outlet concentrations as these were found to be below 10 mg/l in most cases and the threshold limit of 15 mg/l was never exceeded. Treatment efficiencies were on average 78%.

Ammonium levels into Ormanäs WWTP were on average approximately 20 mg/l. A peak occurred during week 39 when a level as high as 36 mg/l was noted (Figure 15). However, outlet concentrations were found to not exceed 5 mg/l.

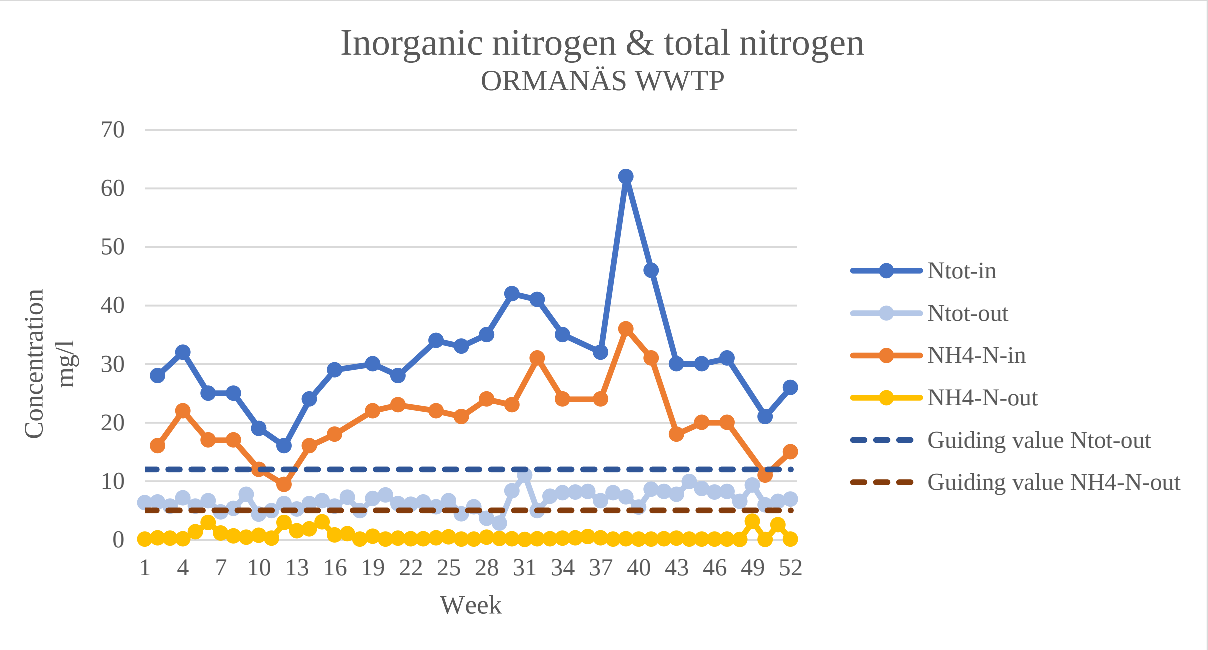

Figure 15 Inlet and outlet concentretions of N_{tot} and NH_4-N at Ormanäs WWTP, the limiting yearly average for N_{tot} outlet concentrations and the guiding value for NH_4-N outlet concentrations.

The results clearly show how the inorganic nitrogen is coupled to the amount of total nitrogen – the inlet concentrations follow the same pattern.

At Ormanäs WWTP drops in the treatment efficiency of both inorganic nitrogen and total nitrogen was noted when corresponding inlet concentrations were at a yearly low. The reason for this was most probably due to the large volumes of excess water giving low concentrations and low temperatures leading to less efficient treatment. Which is also implied by the relatively low inlet concentrations seen for suspended solids, COD and $BOD_{7.}$

<u>Total phosphorous & total suspended solids</u>

On average, the inlet concentration of total suspended solids (TSS) to Lyby WWTP was observed to about 450 mg/l with maximum and minimum levels at 750 mg/l (week 32) and 220 mg/l (week 29) respectively (Figure 16). All outlet concentrations were found to be below the lowest detectable limit of 5 mg/l.

The inlet concentrations of total phosphorous (P_{tot}) to Lyby WWTP were observed to be relatively low during the first 10 weeks of the year (Figure 16). However, an increase from an average concentration of 3 mg/l to 6 mg/l followed by a peak reaching a concentration of 9,4 mg/l during week 35 was noted. Treatment efficiency was at least 97% for the whole year.

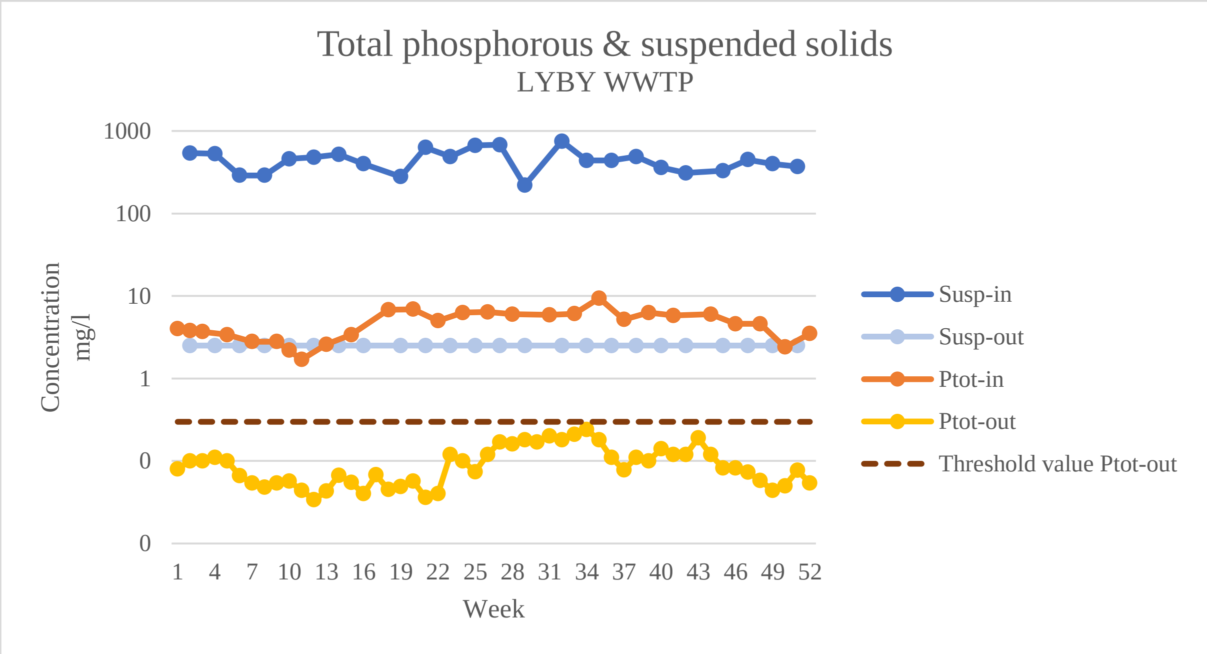

Figure 16 Inlet and outlet concentretions of TSS and P_{tot} at Lyby WWTP along with the threshold value for P_{tot} outlet concentrations. (OBS! Logarithmic scale). Outlet concentrations for TSS were not noted to exceed the detection limit of 5mg/l and are therefore presented as 2,5 mg/l which is half the detection limit.

No clear correlation is seen between inlet concentrations of TSS and P_{tot}.

At Ormanäs WWTP the average inlet concentration of TSS was found to be about 150 mg/l. A peak of 320 mg/l was noted during week 39. During week 30 a relatively high inlet concentration of 300 mg/l was observed coupled with a maximum outlet concentration of 85 mg/l (Figure 17). The treatment efficiency was at the same time at its lowest, 69%.

For P_{tot} the inlet concentrations were observed in the interval of 1 – 6 mg/l with an average level of 3,2 mg/l. Outlet concentrations were found to increase between weeks 10 to 19 (Figure 17). During this period the threshold limit of 0,3 mg/l was exceeded four times. Two occurrences of low treatment efficiencies were also observed within this time frame, week 11 and week 18 with efficiencies of 45% respectively 59%.

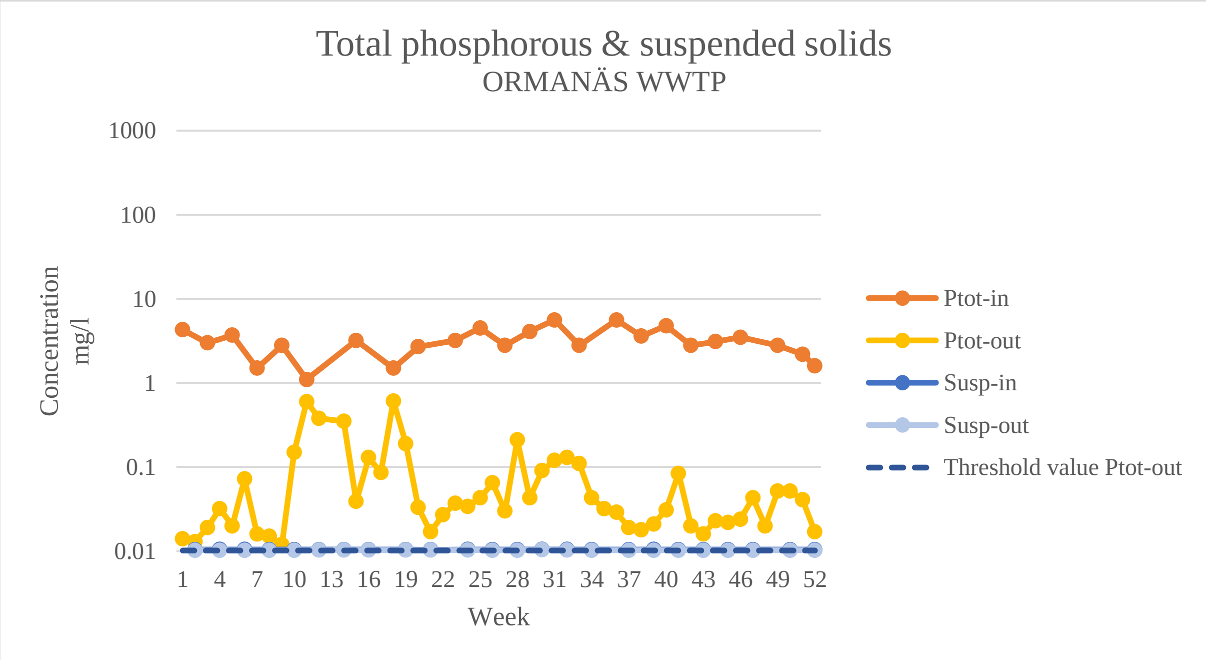

Figure 17 Inlet and outlet concentretions of TSS and P_{tot} at Ormanäs WWTP along with the threshold value for P_{tot} outlet concentrations. (OBS! Logarithmic scale).

The results show how the outlet concentrations are affected when there are large amounts of sludge in the system which clogs the filters – both during March and the summer months there were increased amounts of sludge in the outflow form Ormanäs WWTP.

Heavy metals

The outlet concentrations of heavy metals seen at Lyby WWTP were relatively stable (se Figure 18), and due to the lower number of measurements it was hard to see any clear trends.

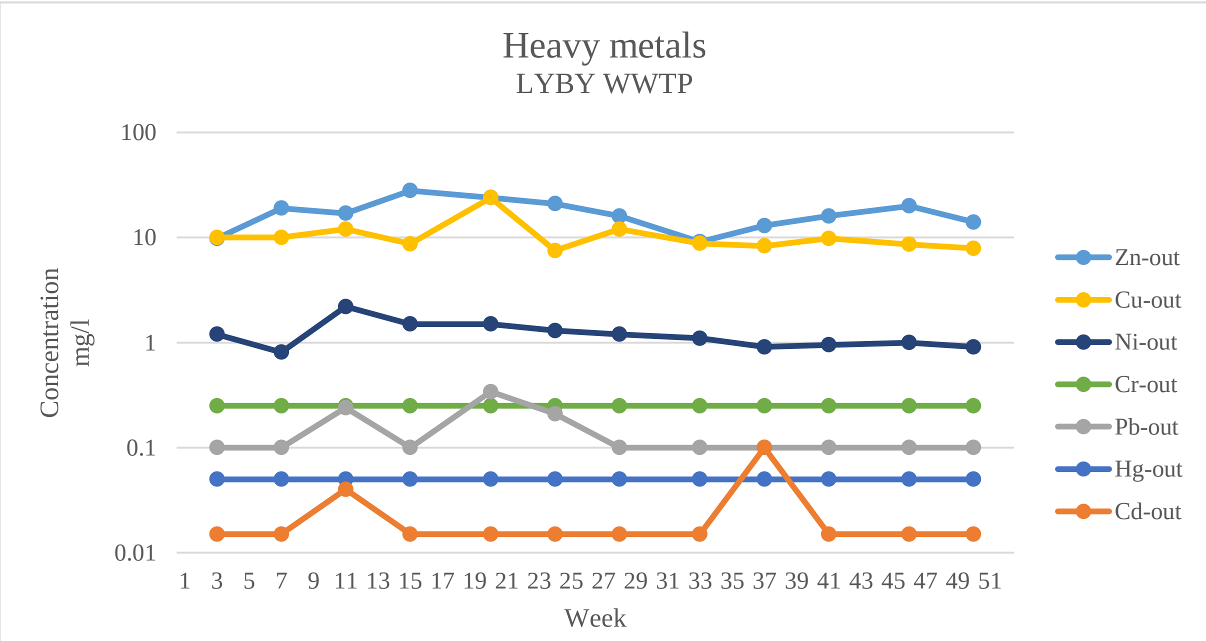

Figure 18 Outlet concentretions of heavy metals at Lyby WWTP. (OBS! Logarithmic scale).

Some "peak" increases are seen, and these could be due to occasional point source effluents to the wastewater system. It is also known that the bedrock around Höör and Hørby contain high amounts of Cadmium and Lead, and peaks in concentration for these substances might then be due to large amounts of drainage water, and as said above the precipitation during February, March, September and October 2019 was normal or above normal, aiding this theory – however this would be more accurate if seen in the inlet concentrations.

15 April – 16 May (week 16-20) the pilot plant at Lyby was operating. This could have given decreased concentrations of heavy metals in the outflow from the WWTP however this is not reflected in the results. One reason for this may be the low concentrations and operation close to the detection limit of the analysis methods.

The same was seen at Ormanäs WWTP – the concentrations of heavy metals in the outflow was relatively stable, se Figure 19.

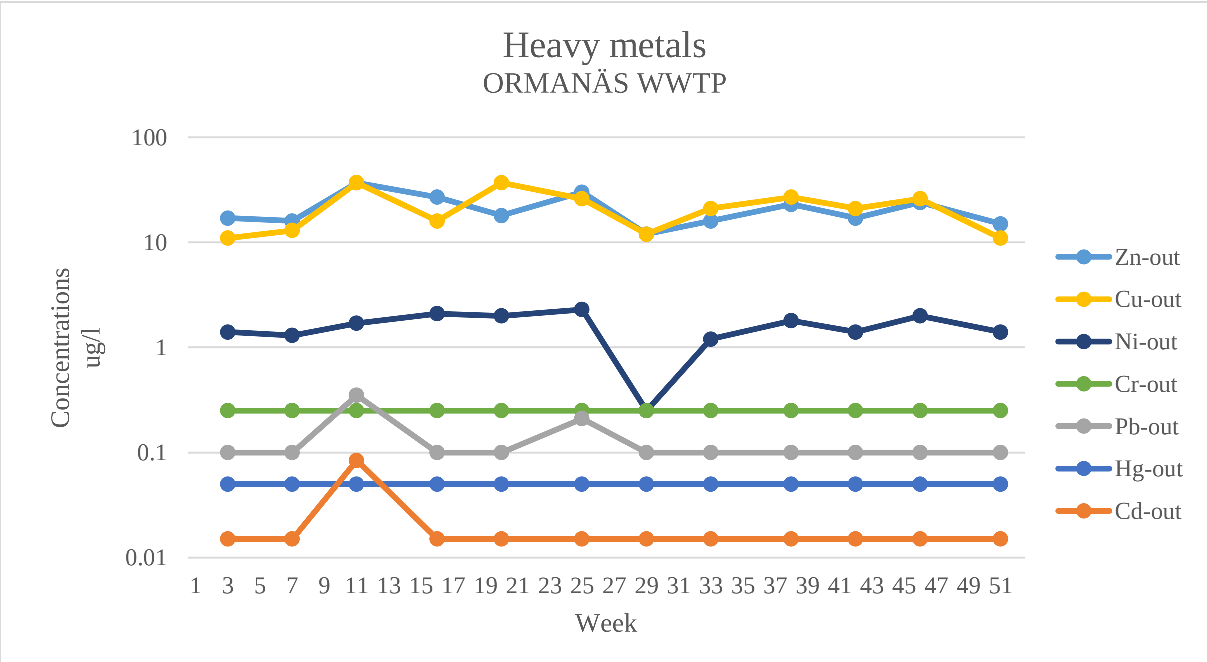

Figure 19 Outlet concentretions of heavy metals at Ormanäs WWTP. (OBS! Logarithmic scale).

Again, some increases are seen, and these could be due to occasional point source effluents to the wastewater system or large amounts of excess water bringing substances from the bedrock into the WWTP.

Organic micropollutants

Phthalates were not measured at neither Ormanäs WWTP nor Lyby WWTP.

2.4. GOLENIÓW WATER AND SEWAGE COMPANY

Biological Oxygen Demand (BOD) & Chemical Oxygen Demand (COD)

The influent concentration of BOD_5 to the Goleniów WWTP was found to be on average 396 mg/l with a maximum level at 625 mg/l in the middle of March and a minimum of 22 mg/l by the end of February (Figure 20). During the sampling in February, treatment levels were at a yearly low of 62%. Outlet concentrations were however never found to exceed 14 mg/l.

Influent and effluent concentrations of COD were observed to be on average 1017 and 35 mg/l respectively. The highest effluent concentration, 67 mg/l, was noted during the beginning of January when treatment efficiency also was at its lowest of 91% (Figure 20).

The influent concentrations of BOD_5 and COD seem to follow the same general pattern and are both highly fluctuating during the year. This may be due to periodical high pollution of organic compounds. Despite the fluctuating inlet values the outlet concentrations were shown to be quite stable, implying that the treatment process is resilient towards varying input

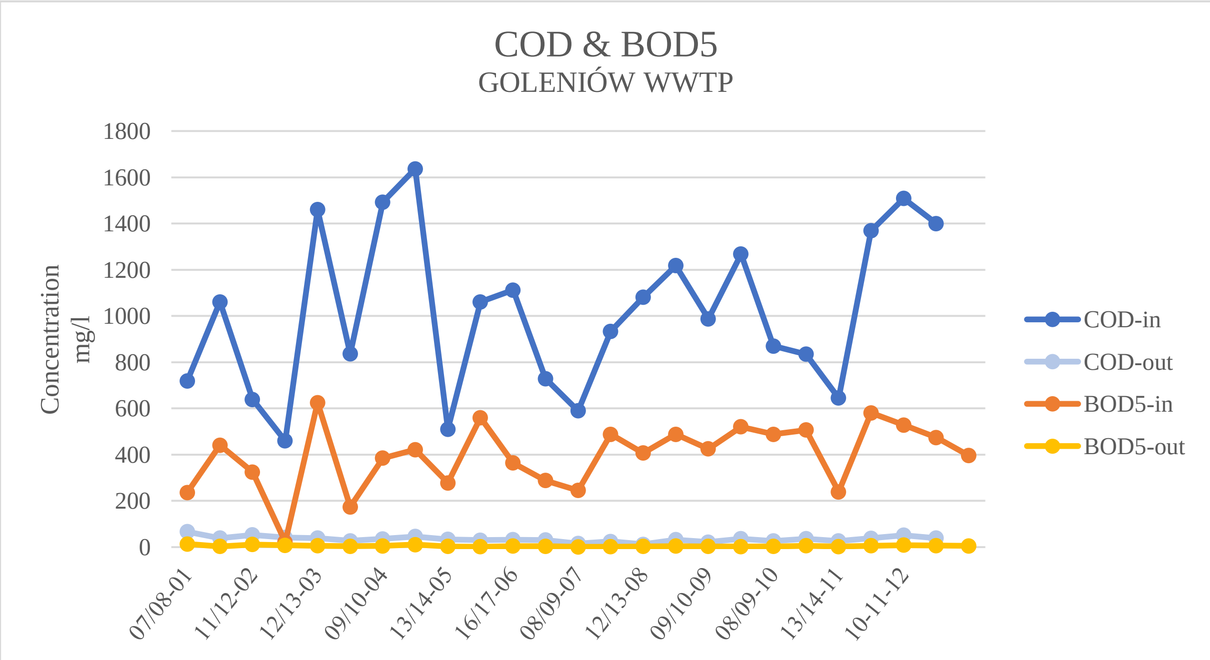

Figure 20 Inlet and outlet concentretions of BOD_5 and COD_{Cr} at Goleniów WWTP

values.

Total phosphorus & total suspended solids

Inlet concentrations of total phosphorus were found to be in general below 20 mg/l except for three occasions. These occurred in the end of January (26 mg/l) as well as in the middle of June (21 mg/l) and the end of November (22 mg/l), see Figure 21. However, on all these occasions the effluent concentrations were observed to be below the average of 0,65 mg/l. This indicates a well-functioning treatment process with regards to phosphorous independent of inlet concentrations. The estimated treatment efficiency was never lower than 88%. June through November seems to have a higher average outlet concentration of total phosphorous than the rest of the year this probably caused by development of filamentous bacteria and foaming in the biological reactor chambers.

The concentrations of suspended solids were found to be on average 358 mg/l in the influent and 6 mg/l in the effluent. Treatment efficiencies never dropped below 93% (see Figure 21). However as for the BOD_5 and COD the concentration of suspended solids is quite fluctuating throughout the year.

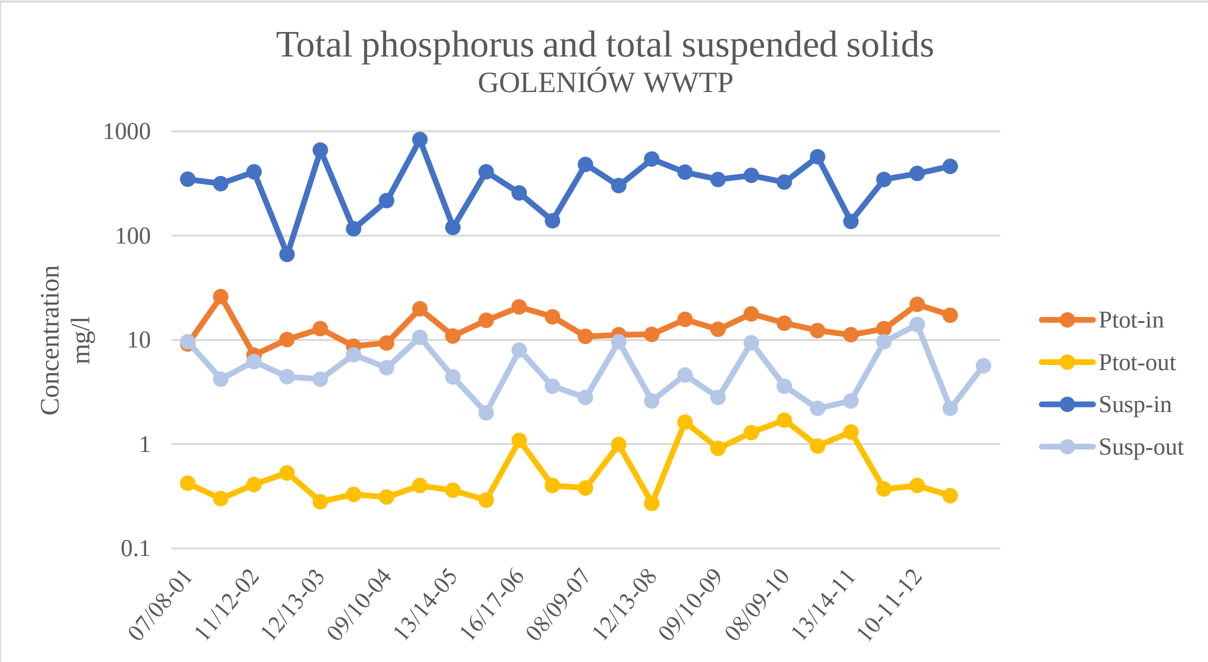

Figure 21 Inlet and outlet concentretions of TSS and P_{tot} at Goleniów WWTP. (OBS! Logarithmic scale).

Total nitrogen

Average inlet and outlet concentrations of total nitrogen were found to be 70 and 10 mg/l respectively. On one occasion, influent levels above 100 mg/l was noted (30/31 of January, 103 mg/l), see Figure 22. Treatment efficiencies were estimated to be in the interval 77-93 %. Despite fluctuating inlet values the outlet concentrations were shown to be quite stable, implying that the treatment process is resilient towards varying input values.

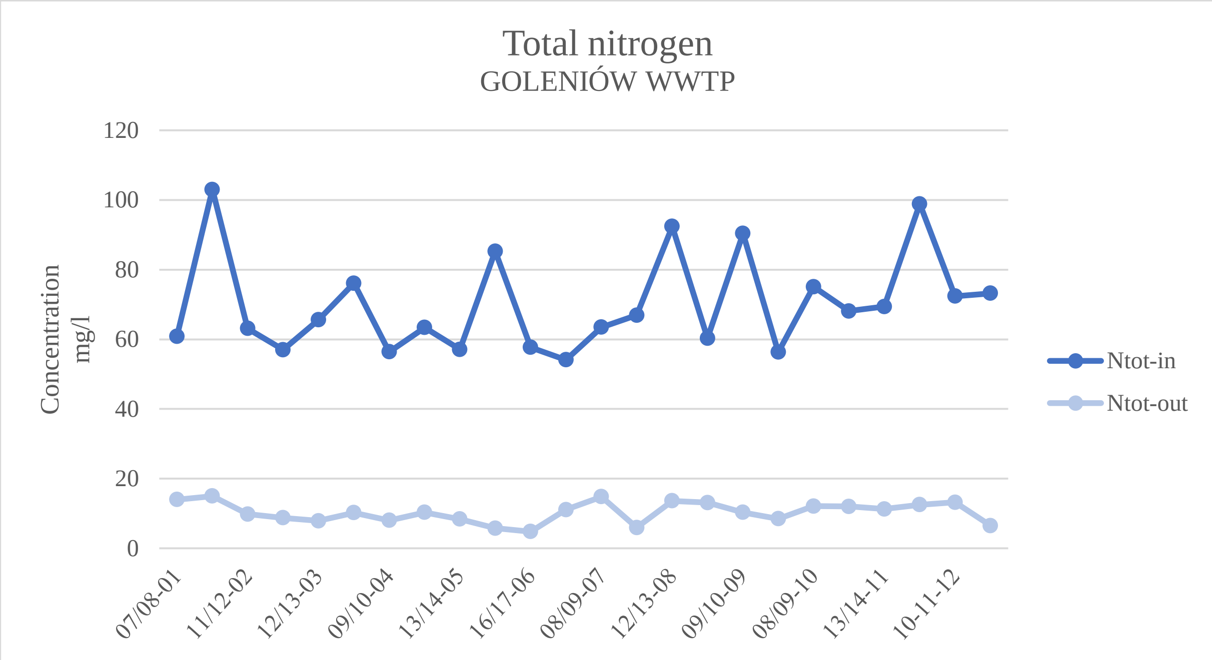

Figure 22 Inlet and outlet concentretions of total nitrogen at Goleniów WWTP.

Heavy metals

Metals in the wastewater are tested once a year. Over a period of 5 years, both the inlet and outlet parameters showed a constant, very low level of the content of the given parameters in sewage, see Figure 23 - Figure 25. Thisis directly connected with the catchment area of the Goleniów wastewater treatment plant, where there are no heavy industry plants that would generate large quantities of particularly harmful compounds for the environment. In order to monitor the wastewater flowing to the treatment plant in Goleniów, the company carries out regular inspections of industrial plants in Goleniów and the GPP in Lozienica that discharge wastewater to the sewerage system and has a direct impact on the quality of the wastewater through the conditions imposed in the agreements regarding the parameters of the wastewater discharged. Inspections of businesses in the Lozienica GGP area confirm that the majority of wastewater discharged into the sanitary sewerage system is domestic wastewater, wastewater from the food industry or car washes.

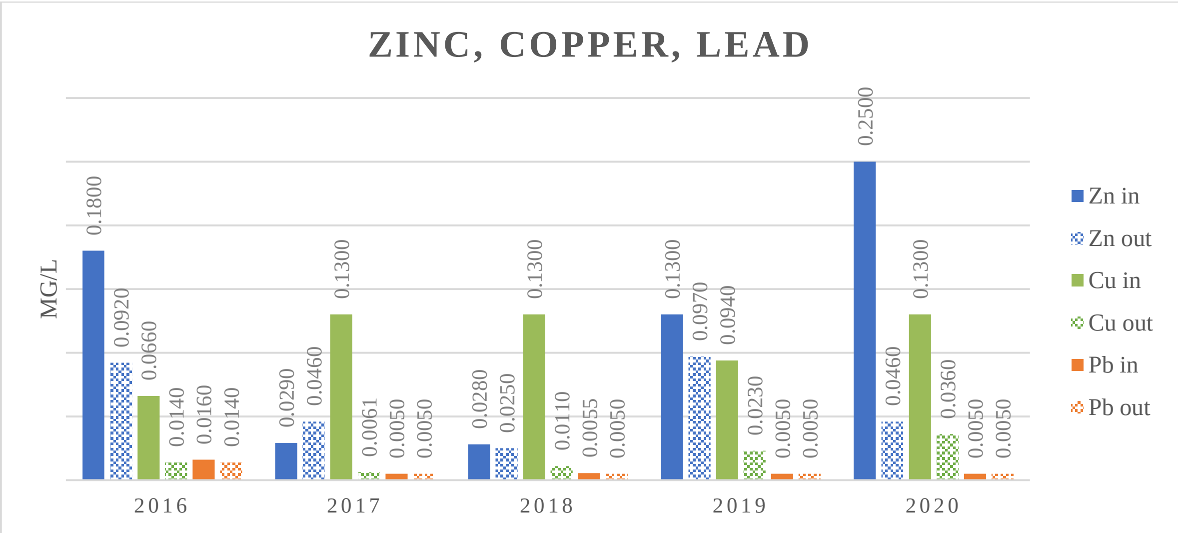

Figure 23 Inlet and outlet concentrations of zinc, copper and lead at Goleniów WWTP.

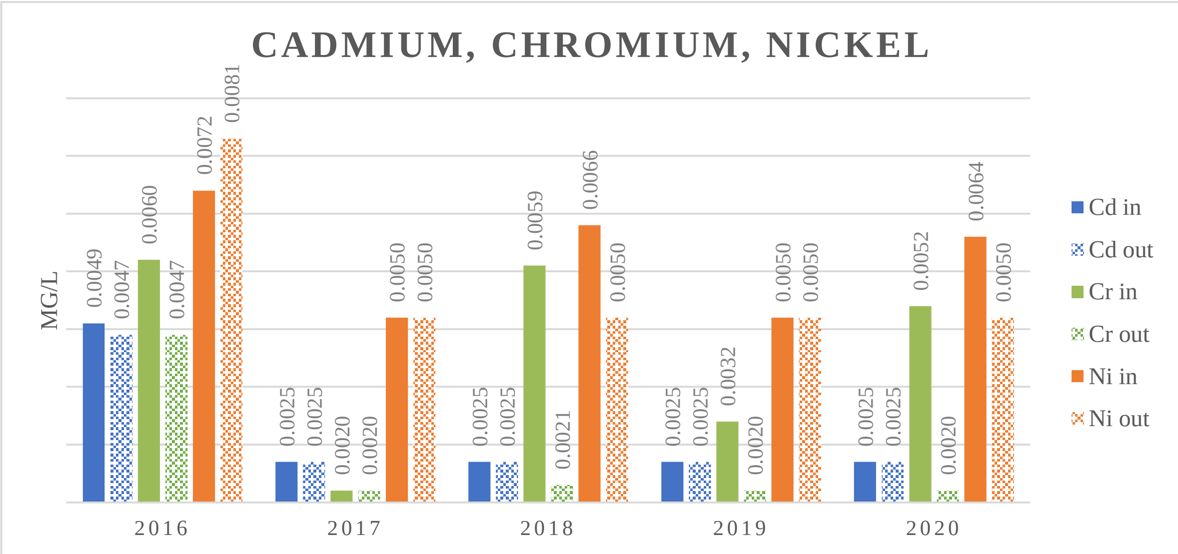

Figure 24 Inlet and outlet conecntrations of cadmium, chromium and nickel at Goleniów WWTP.

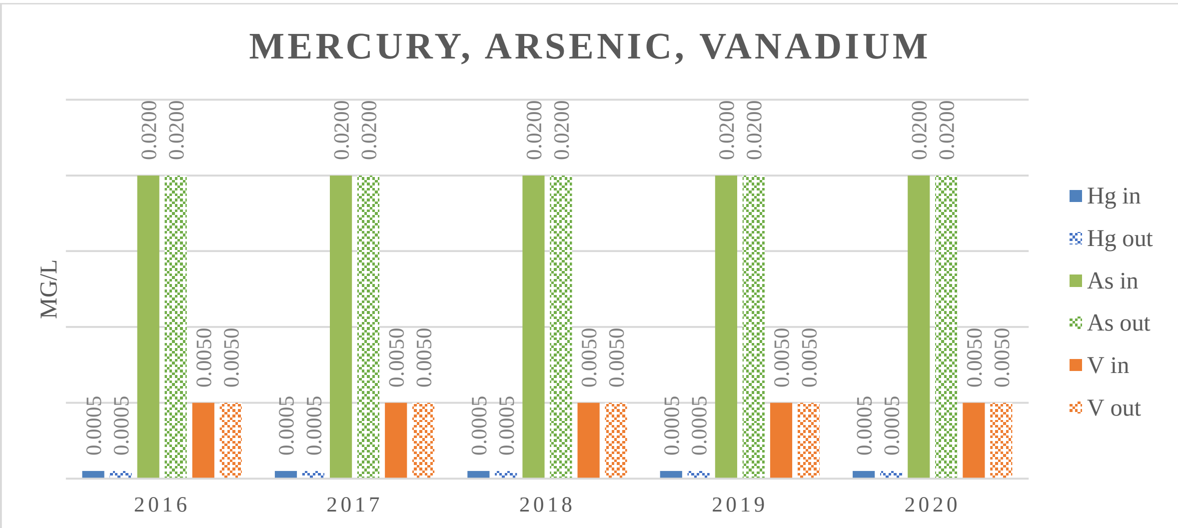

Figure 25 Inlet and outlet concentrations of mercury, arsenic and vanadium at Goleniów WWTP. Concentrations all lie below detection limit.

Organic micropollutants

Analysis and discussion on organic micropollutants are seen in *Study of distribution of PAE in water and sludge.*

2.5. Conclusion wastewater quality assessment

Results from all studied sites showed satisfactory and reliable treatment processes giving effluents with concentrations of nutrients and pollutants which lied below regulatory limiting values. The limiting values vary from country to country, however the limiting values for COD, BOD, total nitrogen and total phosphorous are quite similar between Denmark, Lithuania, Poland and Sweden. For heavy metals on the other hand the limiting values vary more.

The results showed how the treatment processes could be negatively affected by excess water and high inflows to the treatment plants. A more stable flow, and thereby process, showed to give less unwanted substances in the outflow from the treatment plants and gave more nutrients and pollutants in the sludge – which is as wanted from a well-functioning wastewater treatment process.

No clear correlation was seen between the treatment of heavy metals and other measured parameters however as stated above there is an implication that a stable process is preferable – sludge-particles in the outflow give a general increase of pollutants in the outflow. Limiting various substances in the outflow is the goal of the treatment process. It is also important to stress that whatever substances that enter the treatment process either follows the effluent to the recipient or ends up in the sludge - it is therefore important to limit the amount of pollutants that enter the sewage system and limit point sources of pollutants at their origin.

3. SLUDGE QUALITY

3.1. Bornholms Energy & Supply

Dry matter (%)

The dry matter content of dewatered sludge from Rønne WWTP was quite even throughout the year, generally between 22-25 % DM (see Figure 26).

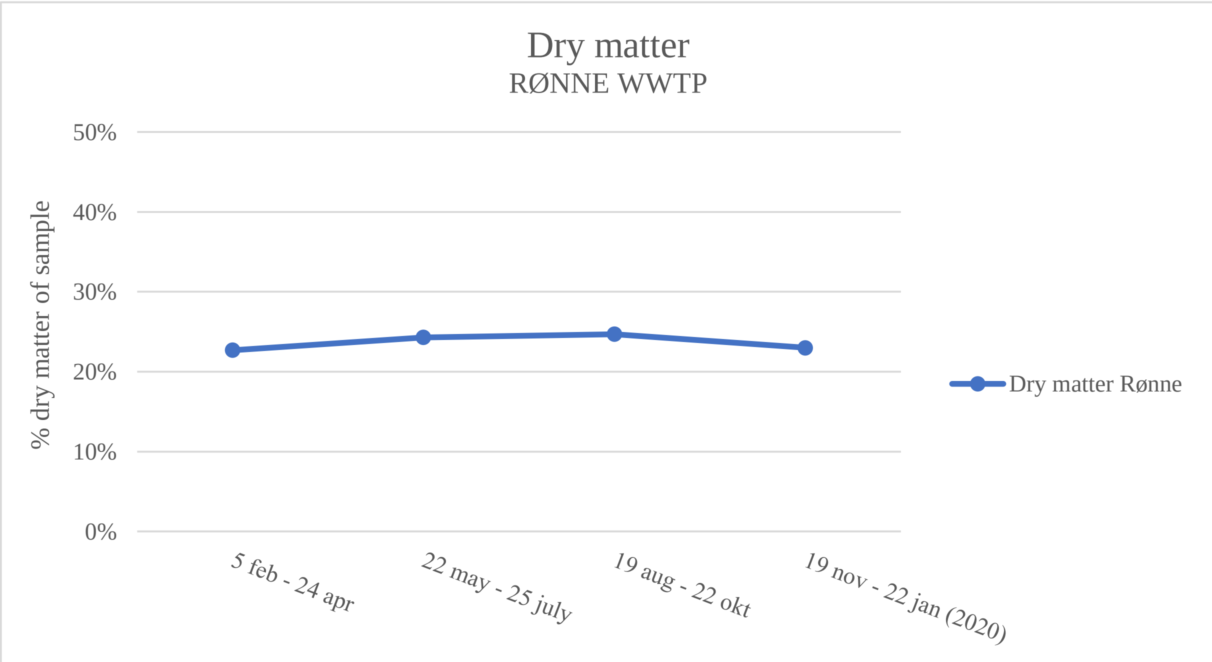

Figure 26 % dry matter of the sludge samples at Rønne WWTP.

Nutrients

The average level of total nitrogen in the sludge at Rønne WWTP was approximated to 50 g/kg dry matter, ranging between 47 - 54 g/kg dry matter, see Figure 27 below. For total phosphorous the corresponding value was approximated 20 g/kg dry matter, ranging between 19-23 g/kg dry matter.

In addition, the sludge showed to contain a significant amount of potassium and sulphur, approximated to 8 g/kg dry matter respectively 9 g/kg dry matter. Both potassium and sulphur are macro-nutrients that benefit plant growth just as like nitrogen and phosphorous.

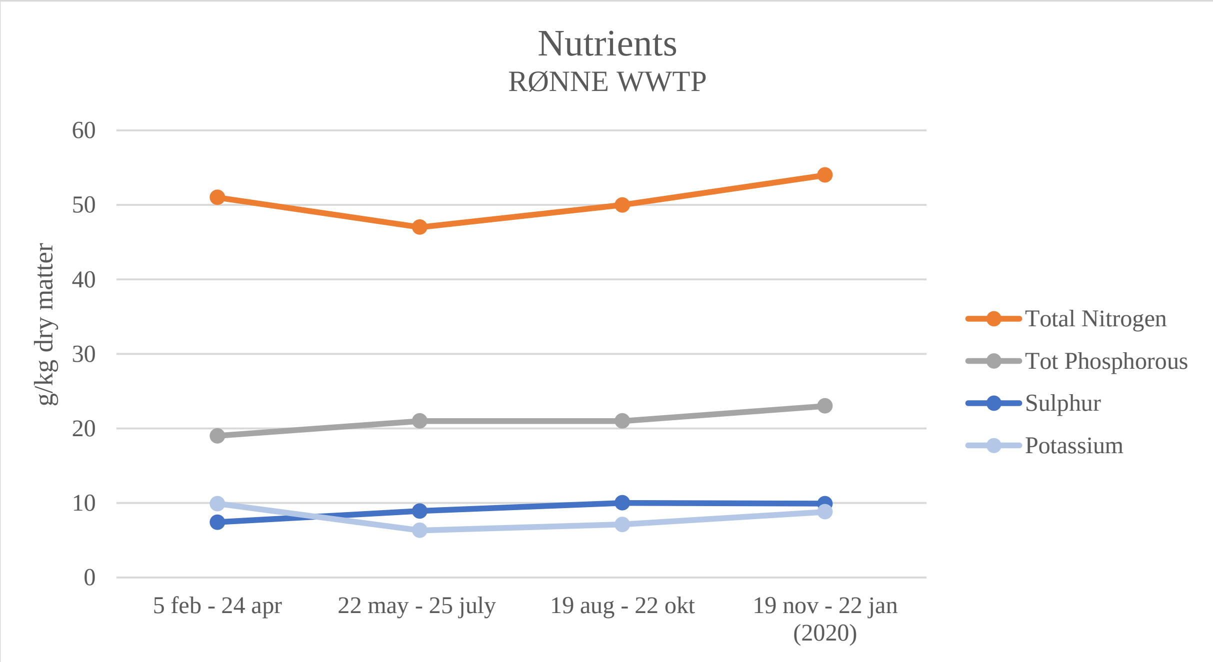

Figure 27 Concentrations of total nitrogen, total phosphorus, potassium and sulphur in the dry matter of the sludge from Rønne WWTP.

The concentration of potassium and total nitrogen seem to have followed the same pattern however, the low frequency of measurements prevents from clarifying any correlations or drawing any clear conclusions.

Heavy metals

Generally, average levels of heavy metals in the sludge were low and stable throughout the year (see Figure 28), reflecting that it is primarily household wastewater that is treated in the WWTP.

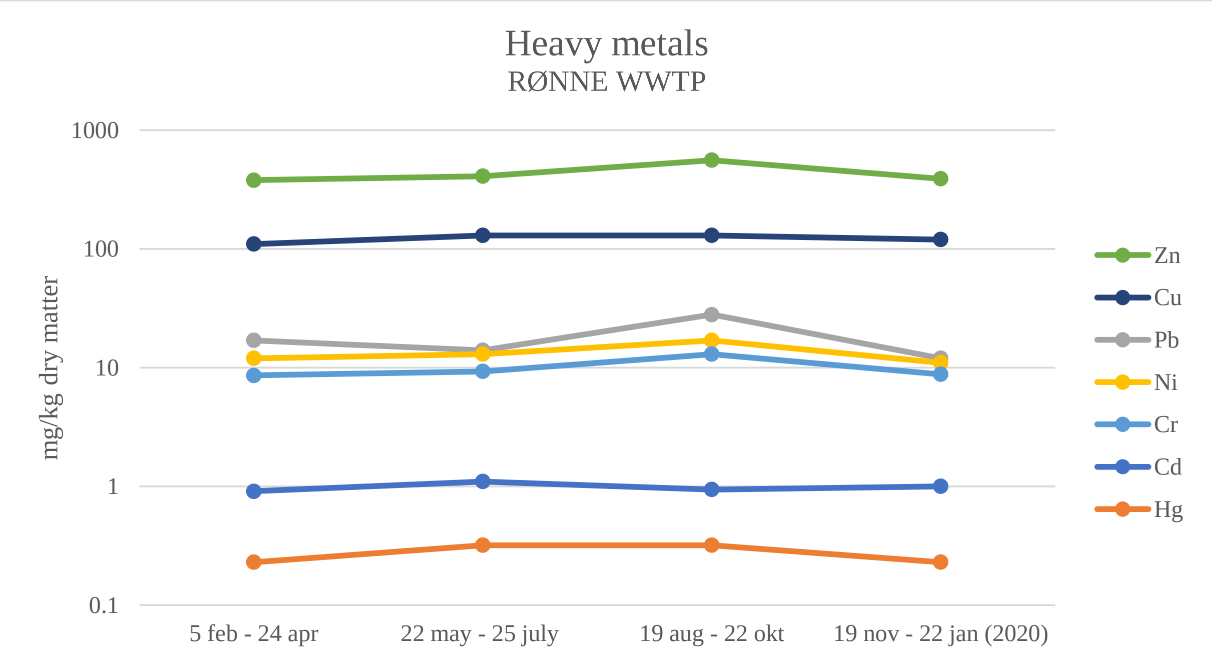

Figure 28 Concentrations of heavy metals in the dry matter of the sludge from Rønne WWTP.

All concentrations, except for cadmium at some occasions, stay below the limiting threshold values.

Organic micropollutants

In Denmark the sludge must be analysed for four groups of micropollutants, which are seen below. Concentrations are presented in Figure 29.

- **LAS:** Linear Alkylbenzene Sulphonates, which are the most extensive used anionic detergents in cleansing agents. LAS are only slowly degradable in anoxic environments and may become concentrated in marine environment. LAS are now on the Danish Environmental Protection Agency’s list of undesirable substances in the group of non-anaerobic degradable substances.
- **PAH:** Polycyclic aromatic hydrocarbons are of interest because of their potential toxic and carcinogenic properties. Due to their low water solubility and their high affinity for organic matter, PAHs are easily concentrated in sewage sludge.
- **NPE:** Nonylphenols are a group of nonionic detergents which are present in many laundry and cleaning agents. Important group of substances in the discussion regarding if the agricultural sector could continue as a receiver of sludge.
- **DEHP:** Diethylhexylphthalat belongs to a group of phthalate esters which is used in large amounts as softener or plasticizer in Polyvinyl chloride (PVC). In soft PVC floorings the DEHP´s are not securely bound in the matrix and can therefore evaporate or wash off from the products or escape into the room as a result of wear. Most of the

DEHP´s in wastewater are decomposed in the WWTP's. But a large amount is also adsorbed in the sludge.

The detection limit for LAS is 50 mg/ kg dry matter, and all measurements from 2019 gave values below the detection limit.

For sumNPE the two first measurements of the year gave values below the detection limit of 0,6 mg/kg dry matter.

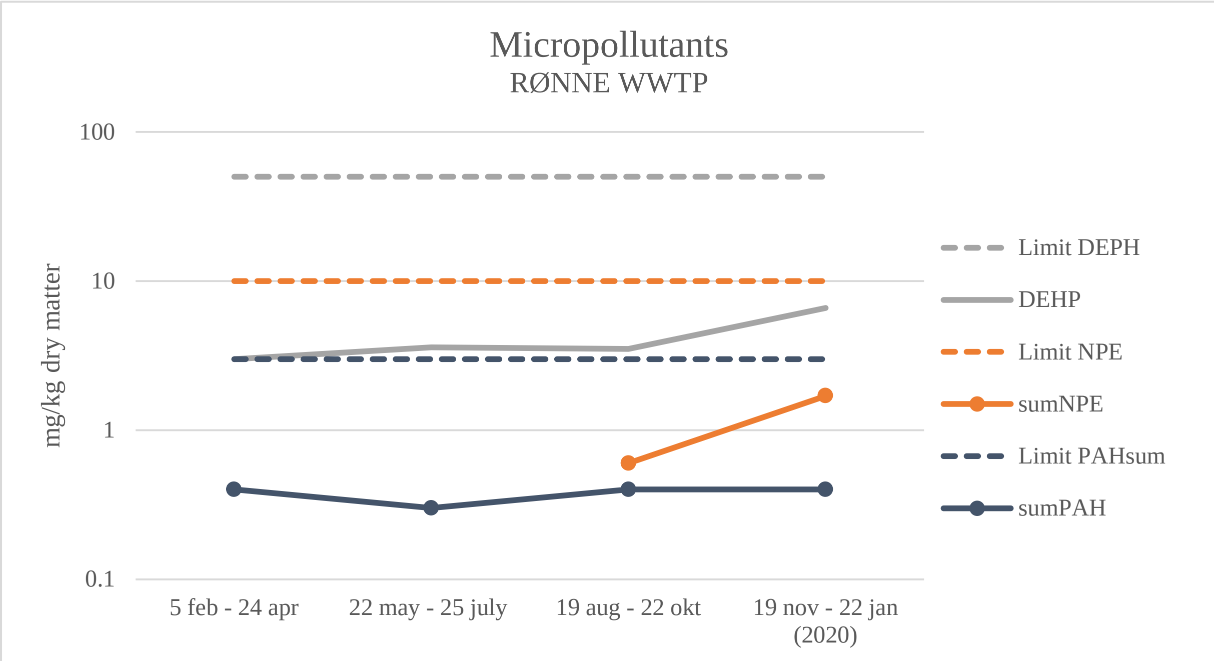

Figure 29 Concentrations of DEHP, sumNPE and sumPAH in the sludge from Rønne WWTP. (OBS! Logarithmic scale). Limitng values for each substance are also showed. For the first two measurements sumNPE was below detection limit and therefore doesn´t show in the graph.

An increase in concentrations was seen towards the end of the year for both DEPH and NPE. This could imply less decomposition of the substances withing the WWTP since the biological processes are slower during winter, however, the low frequency of measurements prevents from drawing any clear conclusions.

All micropollutants in the sludge were found to be below limiting values.

Further analysis and discussion on organic micropollutants are seen in *Study of distribution of PAE in water and sludge.*

3.2. Klaipeda University

Water is the main component of sludge and the amount depends on the sludge sort (primary-, secondary or tertiary sludge) and the way of stabilization (aerobic, anaerobic). The second main component is the dry substance, which is made up of organic and inorganic substances.

Beside the water and dry matter, sludge contains a large variety of components that have been separated from the wastewater. Organic and inorganic elements and compounds, which have its origin in wastewater, sometimes, could be found enriched in the dewatered or dried sludge.

Dry matter (%)

The dry matter content in the dried sludge at the Klaipeda WWTP was quite uniform within 88-98% (see Figure 30).

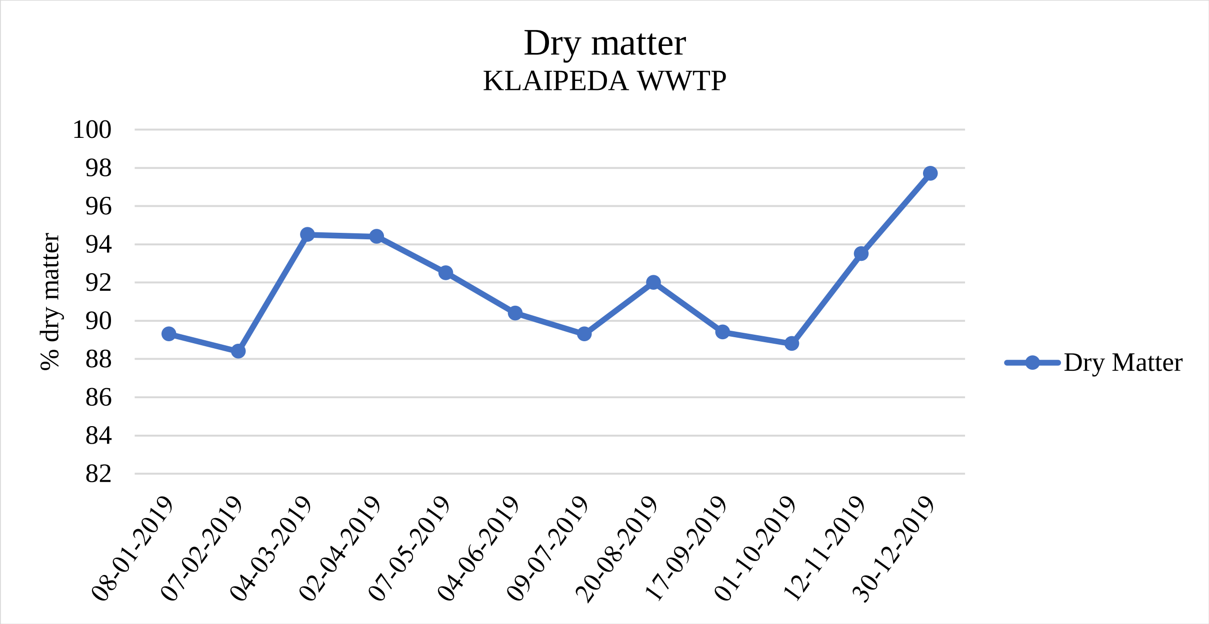

Figure 30 dry matter of the sludge samples at Klaipeda WWTP.

Raw sludge has a water content of 93 % to 99 %. Therefore, dewatering (up to approx. 35 % dry substance content) or drying (to over 85 % dry substance content) can be necessary for further utilization. At Klaipeda WWTP the sludge is dried whilst at the other studied sites the sludge is dewatered giving a higher dry matter content at Klaipeda WWTP.

Nutrients

At Klaipeda WWTP the monthly average level of total nitrogen in the sludge ranged between 47971 and 66644 mg/kg during 2019 (see Figure 31). The corresponding levels of total phosphorus ranged between 27315 and 36500 mg/kg during 2019.

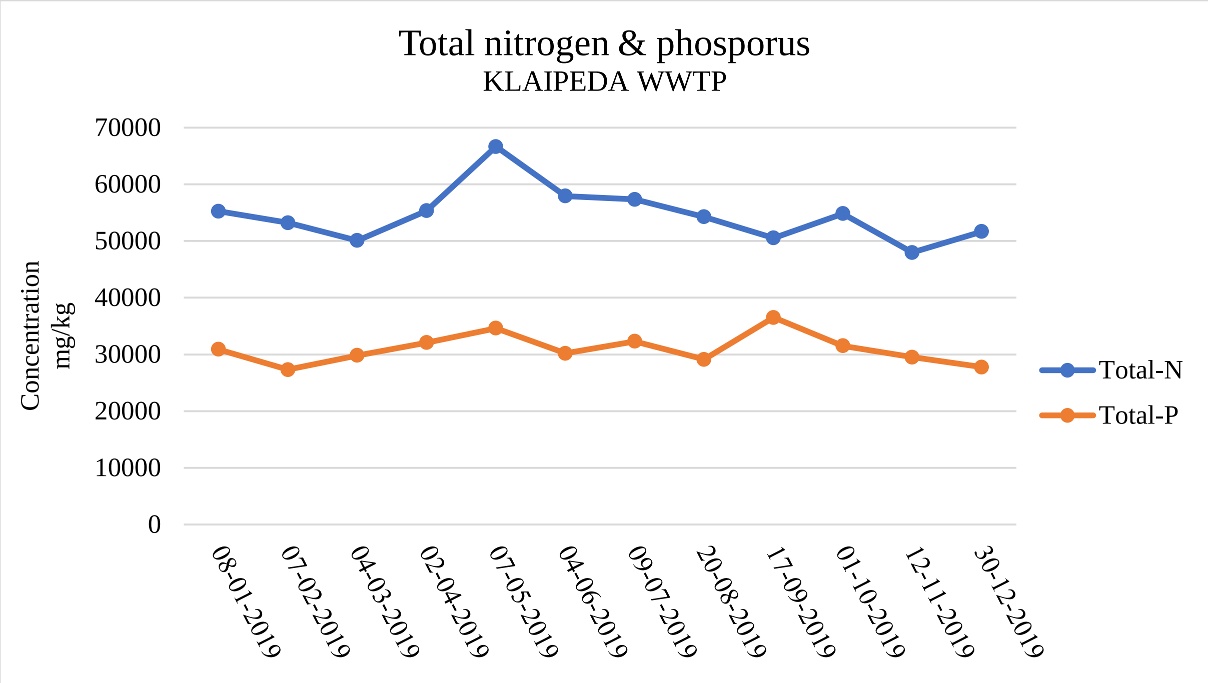

Figure 31 Concentration of total nitrogen and phosphorus in the dry matter of the sludge from Klaipeda WWTP.

The total nitrogen concentrations showed to be sufficient to allow sludge from Klaipeda WWTP as a suitable substrate for soil-enrichment with regards to nitrogen.

The dynamic of the monthly average total nitrogen concentration in the sludge during the last five years is presented in Figure 32. Corresponding dynamic for phosphorus is seen in Figure 33.

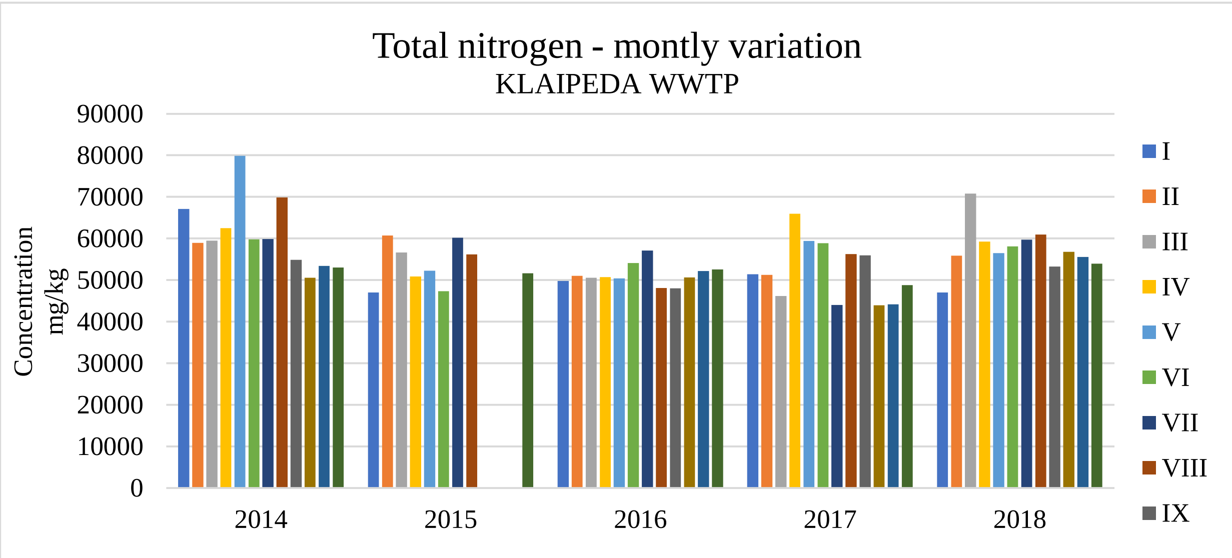

Figure 32 Montly average of total nitrogen concentretions in sludge, Klaipeda WWTP.

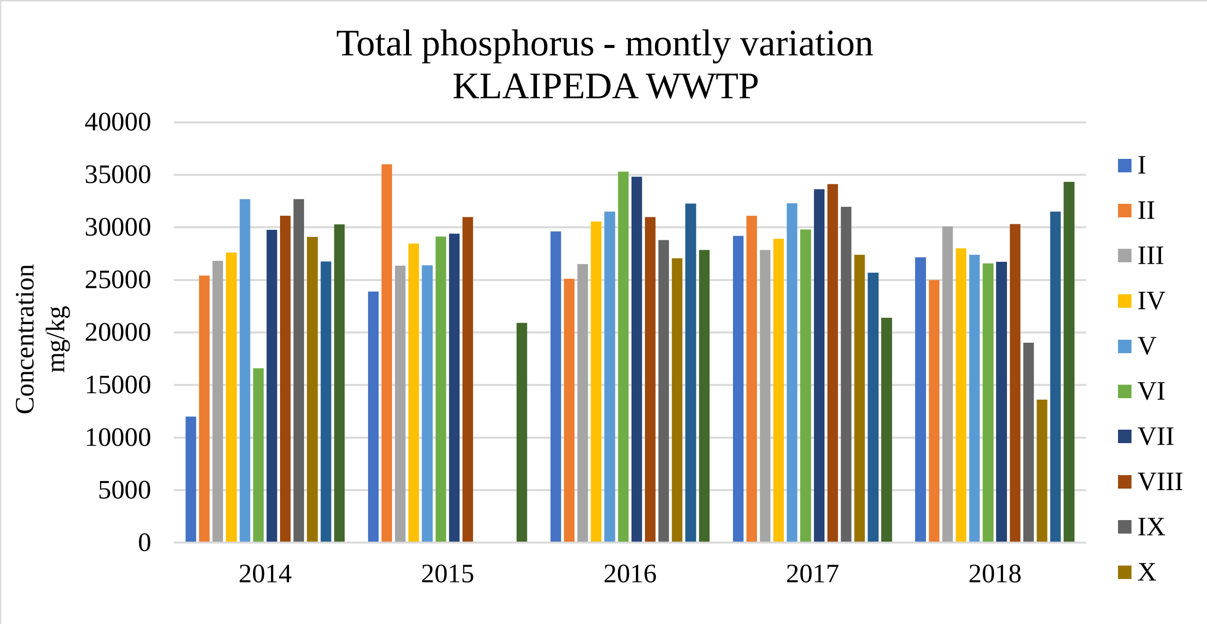

Figure 33 Montly average of total phosphorus concentretions in sludge, Klaipeda WWTP.

The graphs show that every month during different seasons the total nitrogen concentration stays quite stable and high and that every month during all seasons the total phosphorus concentration is sufficient for the usage of sludge as fertilizer.

Potassium and sulphur were not sampled during the year of 2019 and hence no data can be shown from the treatment plant of Klaipeda with regards to these substances.

The sewage sludge has a high fertilizing value like manure, since it is rich in nitrogen and phosphorus. The nutritive elements it contains should be included in the general policy of fertilizers for agricultural lands if the amount of the organic pollutants and heavy metals are in line with national and EU requirements. The analysis of total nitrogen and phosphorus is an important part of the European policy to increase soil fertility and at the same time to protect the environment.

Heavy metals

The copper content of the dewatered sludge from Klaipeda WWTP was quite stable throughout the year with concentrations between 231 and 282 mg/kg, se Figure 34. The corresponding concentration for zinc was between 697 and 952 mg/kg. According to the requirements for wastewater sludge to be used in agriculture in Lithuania (LAND 20-2005), the heavy metals copper and zinc belong to class II, which means that the vegetable or fruit industry cannot use this type of sludge as fertilizer. The requirements are presented in Table 7 in chapter *1. Methods for wastewater & sludge quality assessment*.

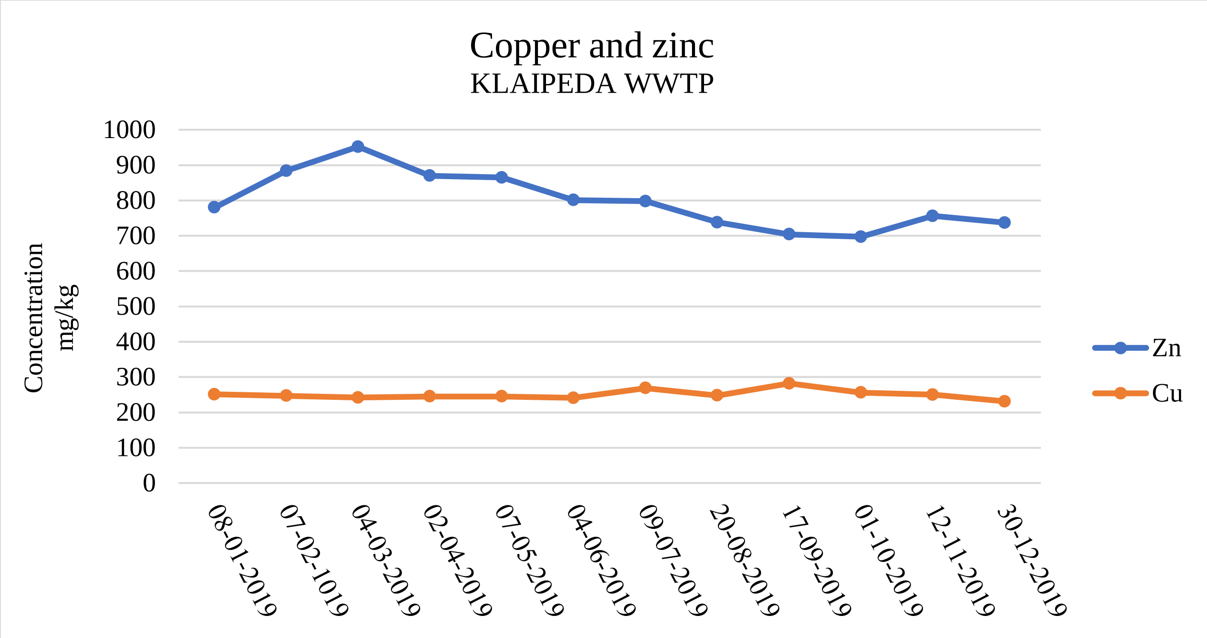

Figure 34 Concentration of copper and zinc in the dry matter of the sludge from Klaipeda WWTP.

The highest concentration of cadmium in the dewatered sludge from Klaipeda WWTP was observed in February 2019, reaching 1.56 mg/kg, and the lowest concentration was 0.75 mg/kg, observed in September 2019, se Figure 35. The reason for the varying cadmium concentrations is mainly due to the industrial pollution sources. The corresponding concentrations for mercury range from 0,26 to 1,2 mg/kg. According to the requirements for wastewater sludge to be used in agriculture in Lithuania (LAND 20-2005), the heavy metals cadmium and mercury also belong to class II. Class II sewage sludge can be used every third year in the same area with the exception of the planting industry of vegetables and fruits used for food. The requirements are presented in Table 7 in chapter *1. Methods for wastewater & sludge quality assessment*.

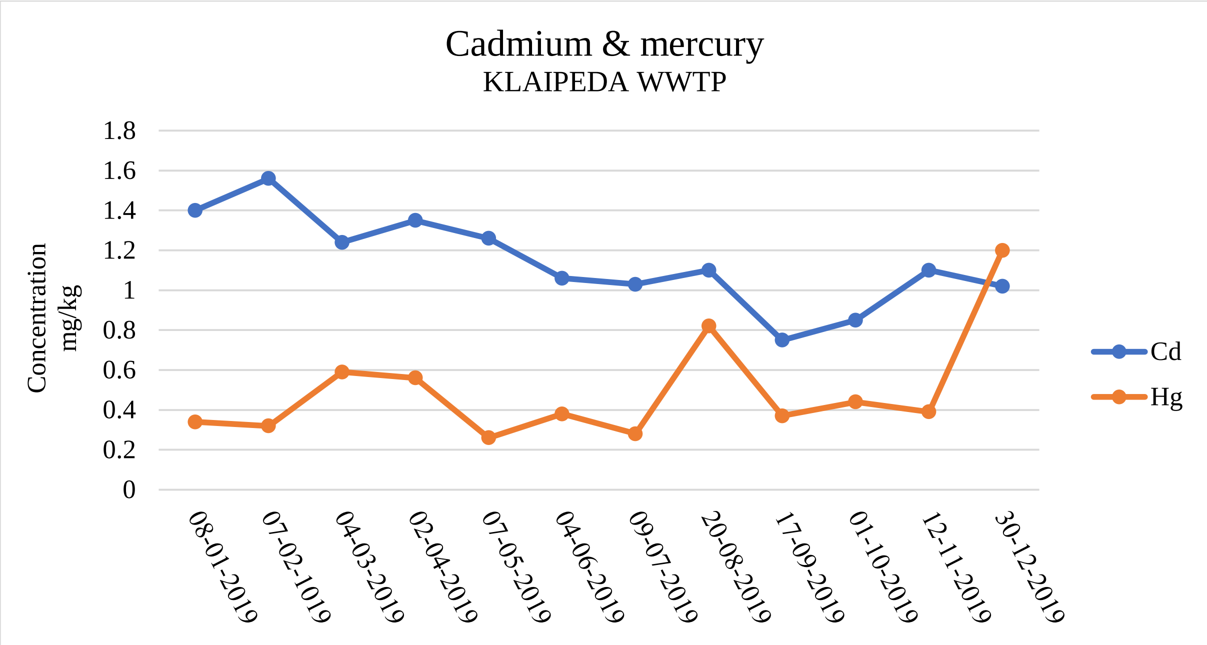

Figure 35 Concentration of cadmium and mercury in the dry matter of the sludge from Klaipeda WWTP.

The chromium content of the dewatered sludge from Klaipeda WWTP ranged between 24,7 and 48 mg/kg, see Figure 36. The nickel and lead concentrations in the dewatered sludge were very similar, the content ranged from 17.4 to 34.3 mg/kg. According to the requirements for wastewater sludge to be used in agriculture in Lithuania (LAND 20-2005), the heavy metals chromium, nickel and lead belong to class I. Class I sewage sludge can be used in agriculture without the restrictions in agriculture and forestry areas. The requirements are presented in Table 6Table 7 in chapter *1. Methods for wastewater & sludge quality assessment*.

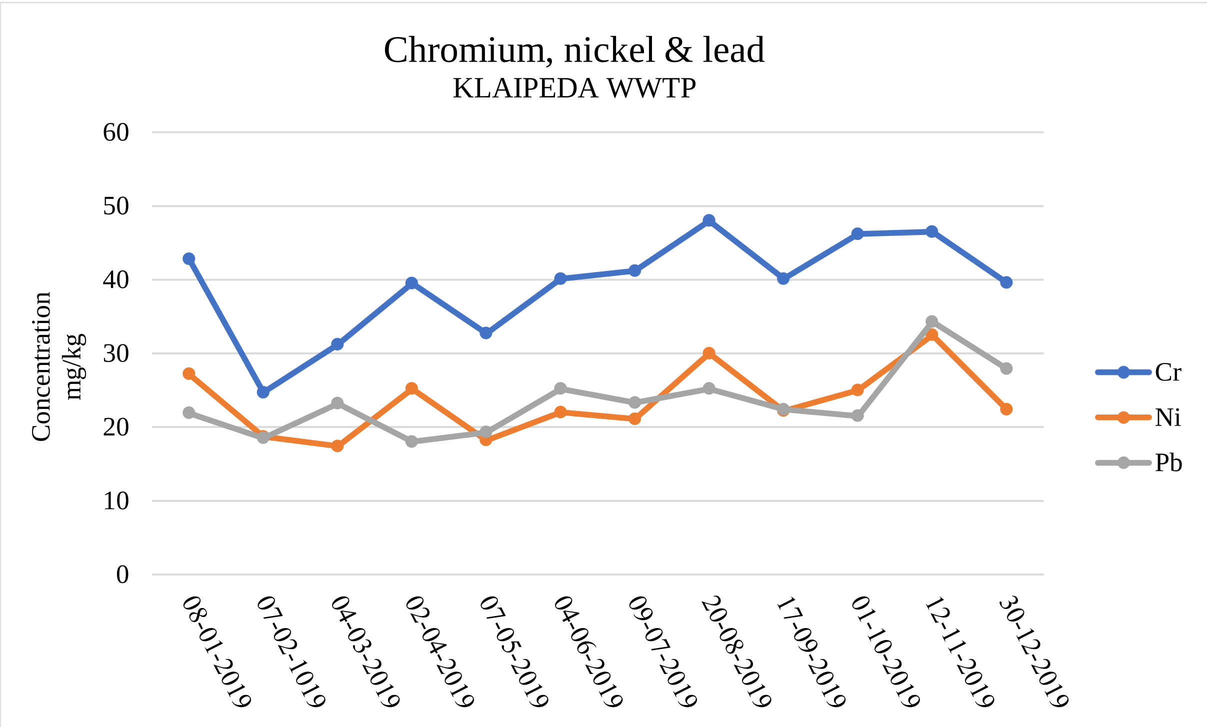

Figure 36 Concentration of chromium nickle and lead in the dry matter of the sludge from Klaipeda WWTP.

The results regarding sludge quality disclosed the potential of the Klaipeda WWTP to produce sewage sludge for further composting and its application capabilities for agriculture fertilization needs. The analysis of the data showed that the concentrations of some heavy metals, such as zinc and copper were slightly high and followingly this sludge fell into class II according to the Lithuanian national legislation (LAND20-2005). The produced sludge contended heavy metal concentrations exceeding the concentrations regulated for class I. These concentrations can be removed applying various heavy metal removing technologies. The compost prepared from sludge of class I can be used for agricultural fertilization needs every year in Lithuania, whilst the compost prepared from class II sludge can be used every 3rd year with some restrictions.

Organic micropollutants

Analysis and discussion on organic micropollutants are seen in *Study of distribution of PAE in water and sludge.*

3.3. The Municipality of Höör / Mittskåne Vatten

Dry matter (%)

The percentage of dry matter in the sludge was seen to be in general lower at Lyby WWTP than at Ormanäs WWTP, see Figure 37. For both treatment plants the percentage of dry matter in the sludge increased during late spring and seemed to decrease again during summer. However, the low frequency of measurements prevents patterns to show in the results and from drawing any clear conclusions.

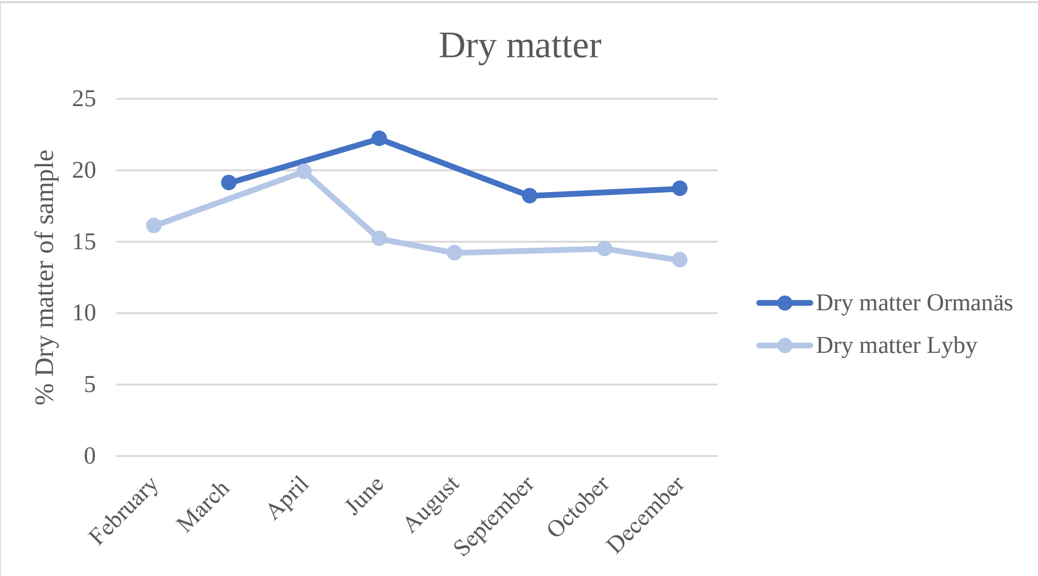

Figure 37 % dry matter of the sludge samples at Ormanäs WWTP and Lyby WWTP.

Nutrients

The concentrations of total nitrogen, inorganic nitrogen and phosphorus in the dry matter of the sludge followed the same pattern at each treatment plant respectively, see Figure 38. At Ormanäs WWTP a decrease in concentrations was seen in June and at Lyby WWTP there was a slight decrease in concentrations in April which rose again in June-August to then decrease slightly again in October. In general, the concentrations at Ormanäs WWTP were less fluctuating than the concentrations at Lyby WWTP.

Potassium and sulphur were not sampled during the year of 2019 and hence no data can be shown from the treatment plants of Lyby and Ormanäs.

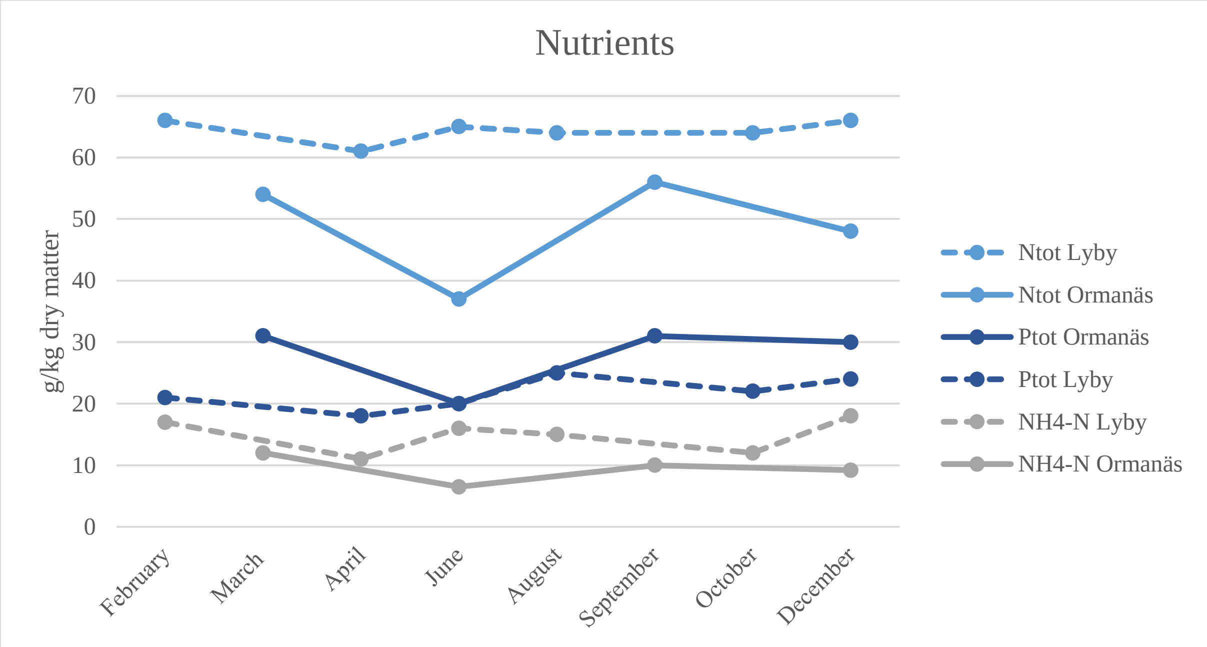

Figure 38 Concentrations of total nitrogen, inorganic nitorgen and phosphorus in the dry matter of the sludge at Ormanäs and Lyby WWTPs. OBS! Logarithmic scale.

As described in the section regarding wastewater there was some troubles with large amounts of sludge in the outflow at Ormanäs WWTP during the summer. This might be reflected in the lowered concentrations of nutrients in the sludge during this period. However, in general, the low frequency of measurements prevents from drawing any clear conclusions.

Heavy metals

The concentration of heavy metals in the dry matter of the sludge was almost without exception higher at Ormanäs WWTP than at Lyby WWTP (see Figure 39). Only chromium was seen in higher concentrations in the dry matter of the sludge at Lyby WWTP than at Ormanäs WWTP. This suggests that the treatment process at Ormanäs WWTP is more efficient by means of heavy metals than the treatment process at Lyby WWTP. Alternatively, the inlet concentrations were higher at Ormanäs WWTP than at Lyby WWTP and the treatment efficiency was equivalent at the both treatment plants however, since no inlet concentrations of heavy metals were measured this could not be checked.

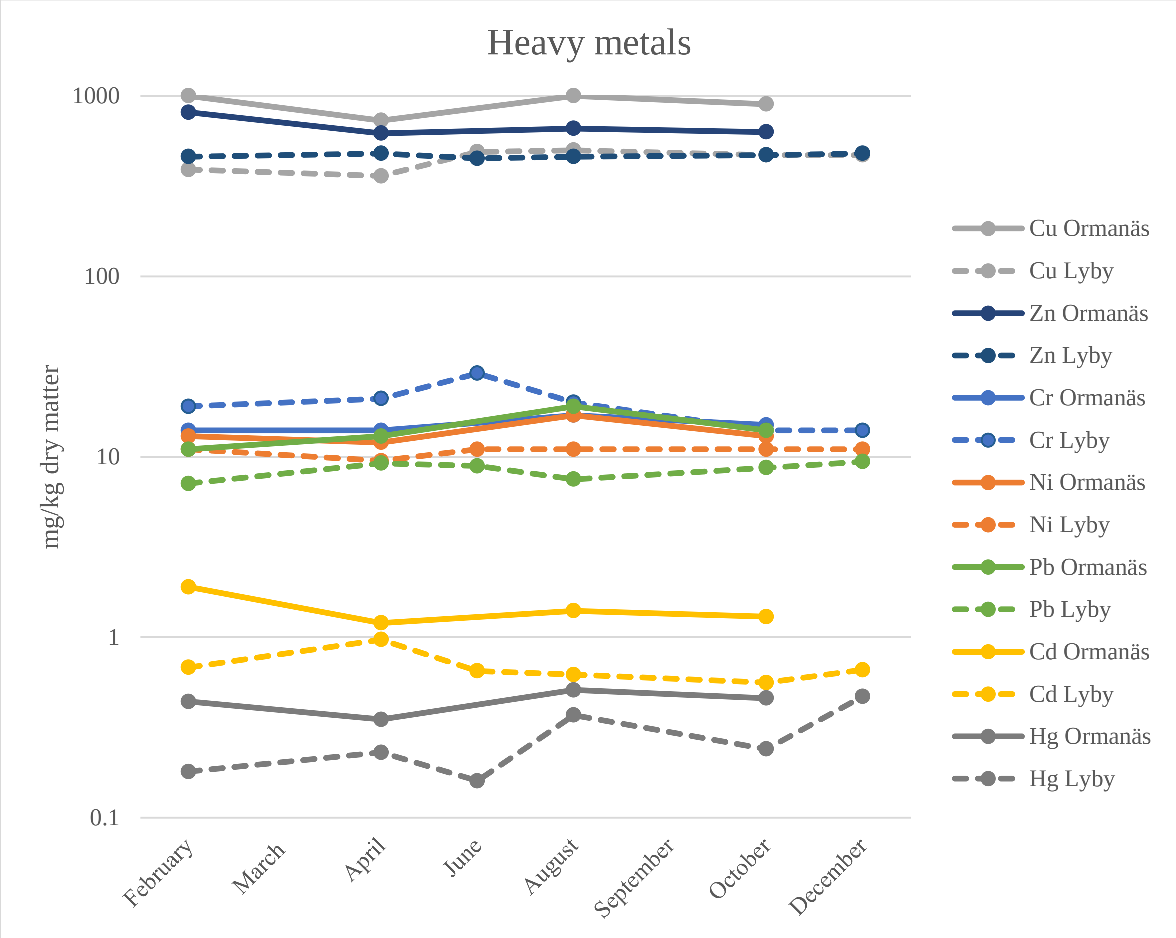

Figure 39 Concentrations of heavy metals in the dry matter of the sludge at Ormanäs and Lyby WWTPs. OBS! Logarithmic scale.

The evaluation of the concentrations of heavy metals in the sludge was clearly limited by the low amount of measurements giving general trends rather than revealing special events. For example, the pilot plant at Lyby was operating 15 April – 16 May and this would theoretically give a decrease of heavy metals in the dry matter during this period. There is a slight implication that the concentrations might have been lower during this period however the frequency of the measurement prevents from drawing any clear conclusions regarding this.

The concentrations generally stay below the limiting threshold values, however, for copper and zinc the threshold limits are occasionally crossed at Ormanäs WWTP. This hinders the sludge from being reused for agricultural purposes.

Organic micropollutants

Phthalates were not sampled during the year of 2019 and hence no data can be shown from the treatment plants of Lyby and Ormanäs.

3.4. Goleniów Water and Sewage Company

Dry matter (%)

The dry matter content in the dried sludge at the Goleniów WWTP was quite uniform within 12,5-14,5%, and the organic content of the dried sludge varied between 64 and 81% (see Figure 40).

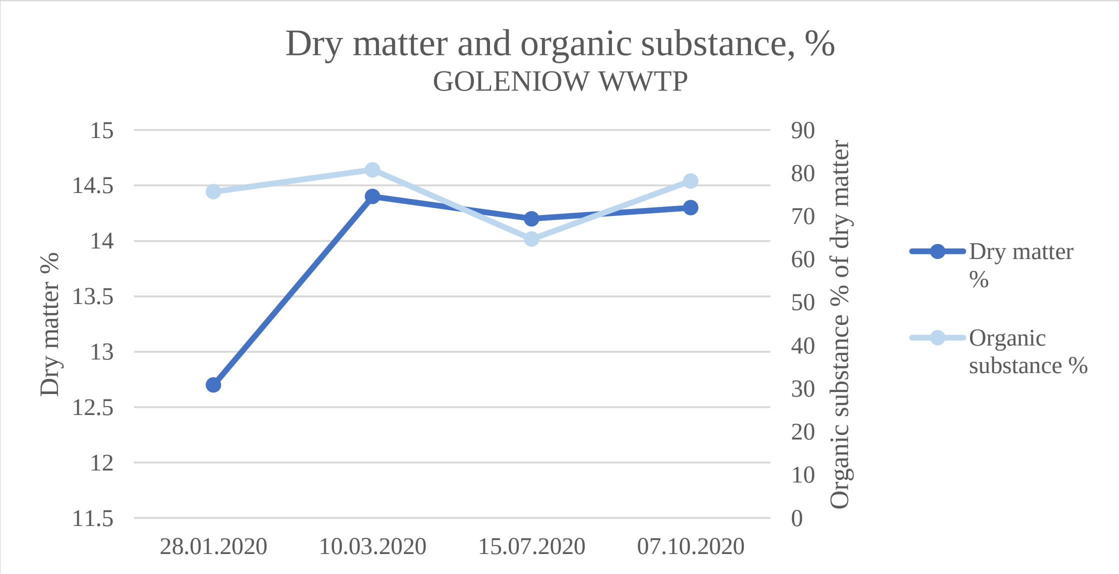

Figure 40 % of dry matter in the sludge and % of organic substance in dry matter at Goleniow WWTP.

Nutrients

At Goleniów WWTP the percentage of total nitrogen in the sludge was about 7% at all the measurement occasions (see Figure 41Figure 31). The corresponding level for phosphorus was about 3%. For the nutrients calcium, potassium and manganese the percentage was about 2%, 1% and 0,7% respectively. Potassium, calcium and manganese are nutrients that benefit plant growth just as like nitrogen and phosphorous.

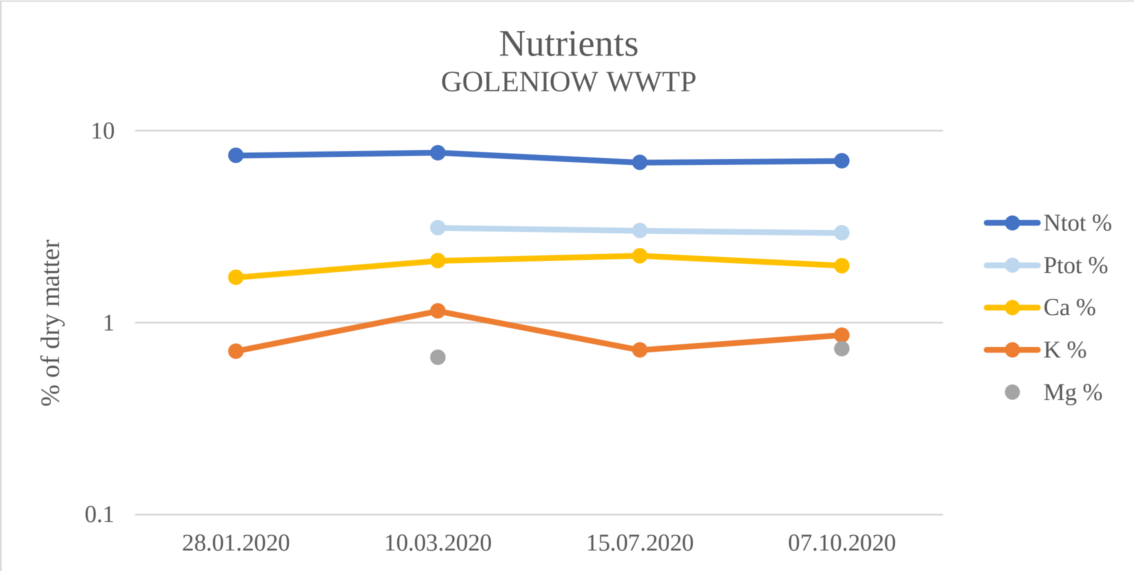

Figure 41 Nutrients as % of dry matter of the sludge at Goleniow WWTP.

Heavy metals

The concentrations of heavy metals ranged from 0,4 mg/kg (mercury) up to 10 g/kg (iron) in the sludge at Goleniow WWTP (see Figure 42)

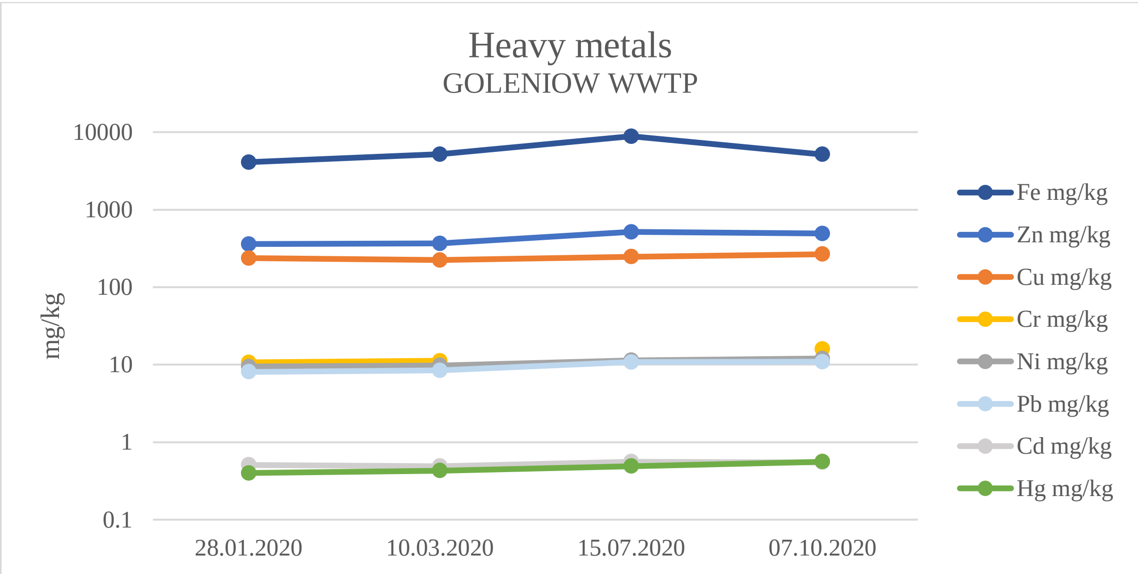

Figure 42 Heavy metal content in sludge at Goleniow WWTP.

Organic micropollutants

Analysis and discussion on organic micropollutants are seen in *Study of distribution of PAE in water and sludge.*

Pathogens

No pathogens were detected at the four measurement occasions.

In the light of the obtained results the tested sludge can be used in agriculture, for land reclamation for agricultural and non-agricultural purposes as well as for land adjustment to specific needs resulting from waste management plans, spatial development plans, for growing plants intended for compost production, for growing plants not intended for consumption and for fodder production. Currently, the sludge is directed to a newly built composting plant using GORECover membranes and processed through the R3 recovery process. The compost resulting from the process has product status and is marketed as a soil improver in accordance with the authorisation of the Minister of Agriculture.

3.5. CONCLUSION SLUDGE QUALITY ASSESSMENT

Sludge is a valuable biomass and as much as possible of the nutrients in the treated wastewater should be collected in the sludge. At the same time as little as possible of the organic matter, heavy metals and chemicals should end up in the treated wastewater and pass on to the recipients – these substances should also be collected in the sludge. However, high concentrations of heavy metals and chemicals in the sludge could restrict the reuse of the sludge. Therefore, it is important to further restrict the use of heavy metals and persistent chemicals and avoid large primary sources of these substances or apply heavy metal reduction technology.

This project has shown that the studied WWTPs are efficient and reliably treat the incoming wastewater. However, residues of the wastewater treatment process that end up in the sludge determine how the sludge can be further used.

At one of the studied WWTPs in Sweden – Ormanäs WWTP – the concentrations of copper and zinc limited the possibility to reuse the sludge during 2019. At Rønne WWTP cadmium concentrations a few times exceeded the threshold limit in relation to dry matter, but it didn’t exceed the Danish threshold limit in relation to phosphorus, and thus the sludge was allowed to be used in agriculture. In Lithuania the different classifications of sludge enabled further reuse since sludge with a wider range of concentrations of heavy metals are allowed for different reuse purposes with different restrictions – except use for agricultural purposes. The same system is used in Poland and with the possibility to reuse sludge for different purposes the compost derived from the Goleniow sludge has product status and is marketed as a soil improver in accordance with the authorisation of the Minister of Agriculture. So, the governing legislation is one of the main limiting factors to the reuse of sludge.

Sewage sludge has a high fertilizing value, since it is rich in nitrogen and phosphorus. The nutritive elements it contains should be included in the general policy of fertilizers for agricultural lands if the amount of the organic pollutants and heavy metals are in line with national and EU requirements. However, since nutrients can have a negative effect on the environment, causing for instance eutrophication of lakes and oceans, there is a limit to the amount of sludge that can be used on arable land also with regards to the surplus of nitrogen and phosphorous, not only organic pollutants and heavy metals. The analysis of total nitrogen and phosphorus is an important part of the European policy to increase soil fertility and at the same time to protect the environment.

4. CONCLUSIONS – THE INFLUENCE OF WASTEWATER QUALITY ON SLUDGE QUALITY

The sludge process is slower than the wastewater treatment process (sludge recirculates and is reused within the wastewater treatment process before taken out as a residue) making it hard to see any direct effects and correlations between what happens in the sludge and what happens in the wastewater. For example, heavy metal pollution from a point source may be clearly seen when analyzing incoming wastewater to the treatment plant but may not be clearly seen as a peak in heavy metal concentration in the sludge but rather a slightly increased level over time.

Again, it is also important to stress that whatever substances that enter the treatment process either follows the effluent to the recipient or ends up in the sludge - it is therefore important to limit the amount of pollutants that enter the sewage system and limit point sources of pollutants at their origin.

Seen from the pilot plan project at Lyby WWTP, where external sludge during a test period was treated separately before the reject water from this process was inserted in the main wastewater treatment process, was that external treatment processes can have a positive effect on the overall treatment in the WWTP. Results from the pilot plan project can be found in report *Main Output WP3 – Pilot plant for external sludge handling.* Since the project was time limited a large impact in the results described in this report was not evident and a further evaluation in relation to both feasibility, efficiency and economical aspect would be needed in order to evaluate an investment in equipment for external sludge handling.

Overall, the results from all studied sites showed satisfactory and reliable treatment processes giving effluents with concentrations of nutrients and pollutants which lied below regulatory limiting values. They also showed how the treatment processes could be negatively affected by excess water and high inflows to the treatment plant. Stable processes showed to give less unwanted substances in the outflow from the treatment plants and gave more nutrients and pollutants in the sludge – which is as wanted from a well-functioning wastewater treatment process.

The results regarding sludge handling showed how the governing legislation is the main limitation to reuse of sludge. A categorisation of sludge allows for a larger fraction of the sludge to be reused for different purposes, whilst stricter regulations limit the reuse of sludge but with the aim to avoid spreading of pollutants etc. To balance the possibilities of reuse and to limit the spread of pollutants is a key question to be addressed by the governing authorities. For further comments on this matter see *Deliverable 3.2 National Sludge Handling Rules – Comparison.*

4.1 Sources of error & limitations

Limits to the project have been for example discrepancies in the analysis methods. Sludge and wastewater samples were not taken at similar intervals – most often wastewater samples are collected more frequently. When comparing trends this then poses a limitation since a lower frequency of measurements gives more general trends rather than revealing special events and correlations. It is therefore hard to directly compare the results in the sludge analysis (fewer samples) with the results in the wastewater analysis (more samples) and draw any direct correlations between them.

During 2020 a great limitation was also the Covid-19 pandemic limiting the possibility to make use of the same sampling techniques and using the same laboratories. Without the same methods for sampling and analysis, as well as maximum allowed concentrations, at all the sampling sites it is hard to make a straight comparison.