

Electronic supporting information (ESI) for

The resilience of constructed wetlands treating greywater: the effect of operating conditions and seasonal temperature decline

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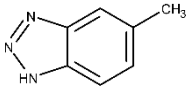
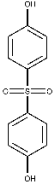
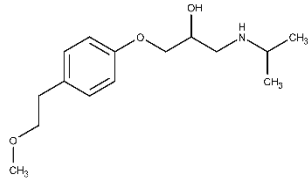
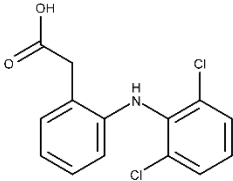
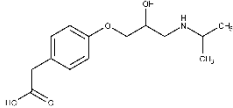
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ESI 1. Properties of the studied compounds

Name	5-Methylbenzotriazole	Bisphenol S	Metoprolol	Diclofenac	Metoprolol acid
Molecular Formula	$C_7H_7N_3$	$C_{12}H_{10}O_4S$	$C_{15}H_{25}NO_3$	$C_{14}H_{11}Cl_2NO_2$	$C_{14}H_{21}NO_4$
Molecular Structure					
CAS no.	136-85-6	80-09-1	51384-51-1	15307-86-5	56392-14-4
pKa	8.5 (anionic form at pH > 8.5)	7.3 (anionic at pH > 7.3)	9.56 (cationic form at pH < 9.56)	4.15 (anionic form at pH > 4.15)	3.50 (cationic form at pH < 3.5; zwitterionic at pH 3.50-9.70; anionic at pH > 9.7)
log Kow	1.89	1.65	1.88	4.51	-1.5
Molecular weight	133.15	250.27	267.36	296.1	267.32
Henry's law coefficient (at 25 °C)	$3.14 \times 10^{-7} \text{ atm m}^3 \text{ mol}^{-1}$	$2.7 \times 10^{-15} \text{ atm m}^3 \text{ mol}^{-1}$ at 25 °C	$2.1 \times 10^{-11} \text{ atm m}^3 \text{ mol}^{-1}$	$4.73 \times 10^{-12} \text{ atm m}^3 \text{ mol}^{-1}$	
Electrophilicity index	pH 4.5	3.618	3.094	2.605	2.491
	pH 7.5	3.489	2.942	2.603	2.479
Ionization potential	pH 4.5	6.65	6.58	6.31	5.87
	pH 7.5	6.55	6.22	6.31	5.81
References	1	PubChem (accessed in March 2022); Fisher scientific (accessed in April 2022)	PubChem (accessed in March 2022); Fisher scientific (accessed in April 2022)	Fisher scientific (accessed in April 2022)	Fisher scientific (accessed in April 2022)

Sources: PubChem (accessed in March 2023); MarvinSketch software

ESI 2. Analysis of MnOx – detailed results

The EDX analysis of MnOx indicated the following content of 37.0% Mn, 6.7% Fe (by weight) (ESI4). Previously reported XRD analysis of this material showed that the predominant phases were pyrolusite (MnO_2 , PDF card 01-071-0071 with major diffraction line at $28.68^\circ 2\Theta$) and lithiophorite ($(\text{Al,Li})\text{Mn}^{4+}\text{O}_2(\text{OH})_2$, PDF card 00-041-1378 with major diffraction line at $18.81^\circ 2\Theta$). The sample decomposition showed that more than 50% dry weight consisted of Mn. The point of zero charge (pH_{pzc}) of the MnOx was 4.8 and for the sand it was 5.9².

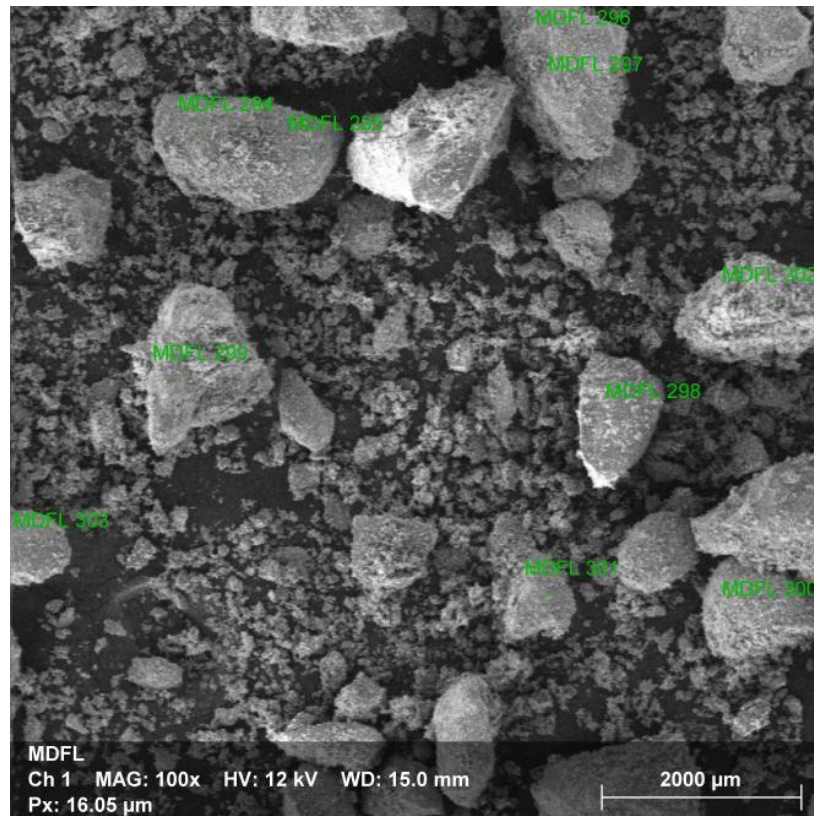
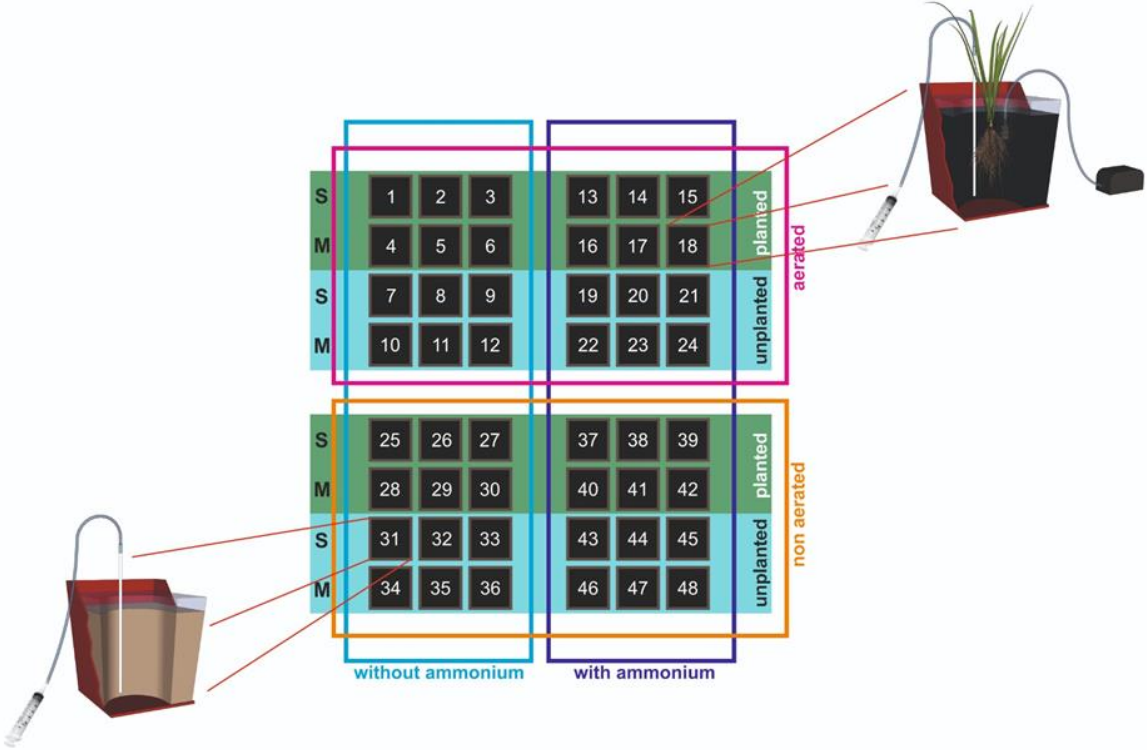


Figure ESI 2. SEM image with the indication of the analysed areas.

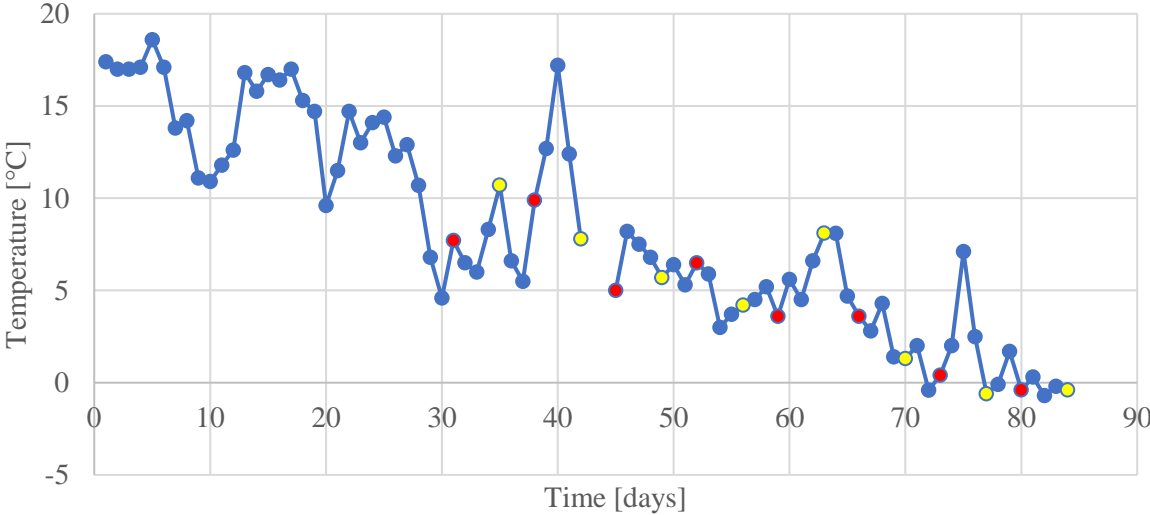
Table ESI 2. Elemental composition (normalized weight percentage) of the selected areas.

	C	O	Na	AL	Si	K	Ca	Mn	Fe
MDFL 294	1.00	5.51		3.83	3.88		3.82	34.46	9.50
MDFL 295	1.34	21.89	0.45	7.11	4.49	1.23		35.47	7.23
MDFL 296		9.05			3.80	1.36		47.11	8.19
MDFL 297	1.59	24.91			2.20			34.80	
MDFL 298	2.42	45.42			39.53				
MDFL 299	1.94	26.20	0.51	2.31	1.50	2.30		50.46	
MDFL 300	3.14	33.06			1.73			29.28	4.08
MDFL 301	1.54	21.60	0.58	4.06	3.46	0.92		39.36	6.85
MDFL 302	1.61	35.48	2.52	4.59	11.35		1.14	23.86	3.79
MDFL 303	1.28	17.31	0.88	6.15	4.05	1.15		38.68	7.18
Mean	1.76	24.04	0.99	5.44	7.60	1.39	2.48	37.04	6.69

ESI 3. Configuration and photo of the experimental setup.



ESI 4. Temperature timeline of the study conducted for 84 days between September to December 2021 in an outdoor setting on the campus of Czech University of Life Sciences Prague. Red and yellow dots indicate the start and end of each batch, respectively.



ESI 5. Concentration and removal of standard parameters.

Parameter	Descript or	Influent		Effluent															
		Inflow +Am	Inflow -Am	S+P+A+Am	S+P+A-Am	S+P-A+Am	S+P-A-Am	S-P+A+Am	S-P+A-Am	S-P-A+Am	S-P-A-Am	M+P+A+Am	M+P+A-Am	M+P-A+Am	M+P-A-Am	M-P+A+Am	M-P+A-Am	M-P-A+Am	M-P-A-Am
DOC	Median	16.27	16.55	16.25	15.79	23.03	26.56	17.58	18.55	20.15	18.32	7.90	8.34	10.09	10.75	10.33	8.09	9.51	9.52
	MAD	0.59	0.93	2.31	3.28	4.26	8.08	1.42	3.30	1.84	2.19	1.64	1.29	0.99	0.81	1.02	1.33	0.47	1.38
	Removal			0%	5%	-42%	-60%	-8%	-12%	-24%	-11%	51%	50%	38%	35%	37%	51%	42%	42%
DIC	Median	9.26	9.43	17.18	10.57	37.86	51.65	7.72	6.27	19.85	20.39	0.51	0.00	0.98	2.51	0.00	0.00	0.00	0.00
	MAD	0.82	0.75	8.44	2.20	6.43	15.08	4.36	5.65	1.23	1.83	0.51	0.00	0.98	1.57	0.00	0.00	0.00	0.00
	Removal			-86%	-12%	-309%	-448%	17%	33%	-114%	-116%	95%	100%	89%	73%	100%	100%	100%	100%
TN	Median	41.65	31.11	10.02	3.31	4.24	2.10	32.93	10.88	11.19	5.77	10.74	8.23	16.71	11.69	31.85	18.99	25.80	17.33
	MAD	1.30	10.54	6.87	1.82	1.43	0.77	4.44	7.57	4.28	2.19	6.00	3.05	3.34	2.82	3.47	2.26	2.34	2.66
	Removal			76%	89%	90%	93%	21%	65%	73%	81%	74%	74%	60%	62%	24%	39%	38%	44%
N-NH ₄	Median	30.72	20.98	3.58	1.32	2.75	0.93	21.69	5.81	7.47	3.94	6.44	4.21	8.13	5.53	17.82	8.11	9.44	5.36
	MAD	29.71	19.54	3.38	1.20	1.40	0.73	6.06	4.41	4.90	1.89	4.50	1.98	4.87	2.28	5.54	3.87	6.38	3.33
	Removal			88%	94%	91%	96%	29%	72%	76%	81%	79%	80%	74%	74%	42%	61%	69%	74%
N-NO ₃	Median	5.60	5.72	0.44	0.39	0.22	0.18	5.17	1.16	0.28	0.30	2.03	2.78	3.27	3.18	9.93	8.60	8.59	8.67
	MAD	0.95	0.62	0.38	0.37	0.17	0.17	0.61	1.12	0.18	0.26	1.18	1.07	0.65	0.72	2.03	1.18	1.23	0.76
N-NO ₂	Median	0.01	0.02	0.02	0.01	0.00	0.00	0.08	0.04	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.00	0.00	0.01
	MAD	0.01	0.02	0.02	0.01	0.00	0.00	0.08	0.04	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Fluoride	Median	0.11	0.11	0.19	0.18	0.15	0.16	0.22	0.22	0.20	0.19	0.03	0.03	0.02	0.02	0.02	0.03	0.03	0.02
	MAD	0.02	0.03	0.02	0.03	0.04	0.04	0.02	0.03	0.01	0.02	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01
Chloride	Median	97.94	75.29	109.35	96.10	145.78	113.43	122.47	90.50	118.56	96.46	138.34	107.55	133.05	111.84	129.12	100.89	117.34	103.52
	MAD	9.86	6.26	19.22	11.55	5.14	11.18	6.37	17.64	4.60	5.05	15.11	10.02	8.65	10.79	4.43	6.22	4.51	5.31
Phosphate	Median	2.35	2.71	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	MAD	1.68	1.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sulphate	Median	39.30	39.63	60.11	83.23	101.28	84.97	69.56	72.09	116.29	172.42	45.90	46.43	40.36	60.15	21.49	29.72	18.02	32.40
	MAD	8.55	5.50	21.24	20.29	76.00	44.60	11.94	44.98	29.42	55.46	3.89	4.24	4.04	3.96	5.99	6.58	6.38	10.23
Mn total, dissolved	Median	0.02	0.02	1.54	0.82	7.01	5.95	0.25	0.27	6.64	3.85	1.06	0.04	0.30	0.04	0.05	0.02	0.09	0.29
	MAD	0.01	0.02	0.03	0.16	1.89	0.37	0.06	0.04	1.89	0.71	1.14	0.01	0.15	0.01	0.02	0.01	0.02	0.10
Fe total, dissolved	Median	0.10	0.11	1.63	0.05	7.33	7.88	0.02	0.15	6.16	1.78	0.03	0.01	0.11	0.15	0.01	0.01	0.11	0.10
	MAD	0.02	0.01	1.27	0.02	6.13	0.09	0.01	0.16	3.17	0.77	0.04	0.01	0.05	0.01	0.01	0.02	0.05	0.01
pH	Median	7.31	7.29	6.91	7.19	7.03	7.14	7.12	7.12	7.04	7.14	5.74	5.97	5.81	5.96	5.46	5.65	5.48	5.72
	MAD	0.06	0.13	0.13	0.16	0.12	0.11	0.19	0.10	0.21	0.11	0.17	0.16	0.19	0.19	0.15	0.07	0.19	0.16

Abbreviations: MAD – median absolute deviation; DOC - dissolved organic carbon; DIC – dissolved inorganic carbon; TN – total nitrogen.

ESI 6. Concentration and average removal efficiencies of the organic contaminants

Parameter	Descriptor	Influents		Effluents															
		Inflow +Am	Inflow -Am	S+P+A-Am	S-P+A-Am	S+P+A+Am	S-P+A+Am	S+P-A-Am	S-P-A-Am	S+P-A+Am	S-P-A+Am	M+P+A-Am	M-P+A-Am	M+P+A+Am	M-P+A+Am	M-P-A-Am	M+P-A+Am	M-P-A+Am	
5MBTR	Conc. AV	4.04	4.06	2.28	3.79	2.37	4.37	1.45	2.76	1.60	2.67	2.82	3.75	1.98	5.33	2.98	4.15	2.89	4.97
	Conc. SD	0.16	0.18	0.60	0.51	0.83	0.30	0.61	3.66	0.57	0.82	0.62	0.59	0.85	0.65	0.49	0.89	0.75	0.38
	Removal AV			44.1	7.1	42.2	-6.8	64.6	33.0	61.1	34.8	31.1	8.4	51.6	-30.0	27.1	-1.8	29.4	-21.3
	Removal SD			13.5	11.8	9.3	11.9	14.4	17.8	6.1	12.7	11.8	8.0	45.3	22.7	11.0	14.7	18.8	10.4
BPS	Conc. AV	4.65	4.75	1.40	2.93	1.42	3.16	1.10	1.17	1.07	1.78	2.25	2.70	1.48	3.94	2.70	3.55	2.66	4.12
	Conc. SD	0.67	0.65	0.84	1.11	0.94	1.61	0.59	0.71	0.61	0.85	0.95	1.40	0.95	1.96	1.03	1.38	1.15	1.51
	Removal AV			71.7	40.8	70.7	34.7	77.8	76.4	72.4	63.2	54.5	45.6	69.5	18.9	45.4	37.7	43.7	14.6
	Removal SD			13.9	14.8	19.5	27.3	16.1	17.9	27.9	39.2	9.8	19.4	13.5	23.2	12.6	22.0	16.3	30.6
MTP	Conc. AV	1.87	1.90	0.31	0.25	0.28	0.63	0.14	0.12	0.10	0.23	1.38	1.30	1.17	1.58	1.47	1.45	1.60	1.47
	Conc. SD	0.39	0.39	0.27	0.23	0.33	0.18	0.16	0.15	0.13	0.25	0.30	0.29	0.47	0.20	0.33	0.50	0.40	0.23
	Removal AV			84.4	87.4	85.6	67.1	93.1	93.9	95.0	87.8	29.3	33.5	39.6	17.4	24.4	26.0	16.6	22.7
	Removal SD			12.8	13.6	10.3	11.9	12.8	17.8	8.8	12.3	6.5	13.9	6.4	23.1	5.4	18.2	9.6	16.6
DCF	Conc. AV	4.74	4.81	1.89	2.49	1.67	2.78	1.09	0.94	0.98	1.60	0.03	0.06	0.13	0.04	0.04	0.03	0.09	0.02
	Conc. SD	0.38	0.37	0.86	1.24	1.13	1.42	0.70	0.76	0.58	0.90	0.09	0.11	0.27	0.07	0.07	0.07	0.18	0.03
	Removal AV			61.4	49.3	65.4	42.4	77.7	80.9	79.7	67.0	99.4	98.9	97.4	99.3	99.2	99.3	98.2	99.7
	Removal SD			15.7	1.5	21.5	2.0	21.1	3.6	27.7	1.4	12.2	1.2	14.3	0.8	9.4	2.3	16.8	0.5

Abbreviations: 5MBTR, 5-Methylbenzotriazole; BPS, Bisphenol S; MTP, Metoprolol; DCF, Diclofenac.

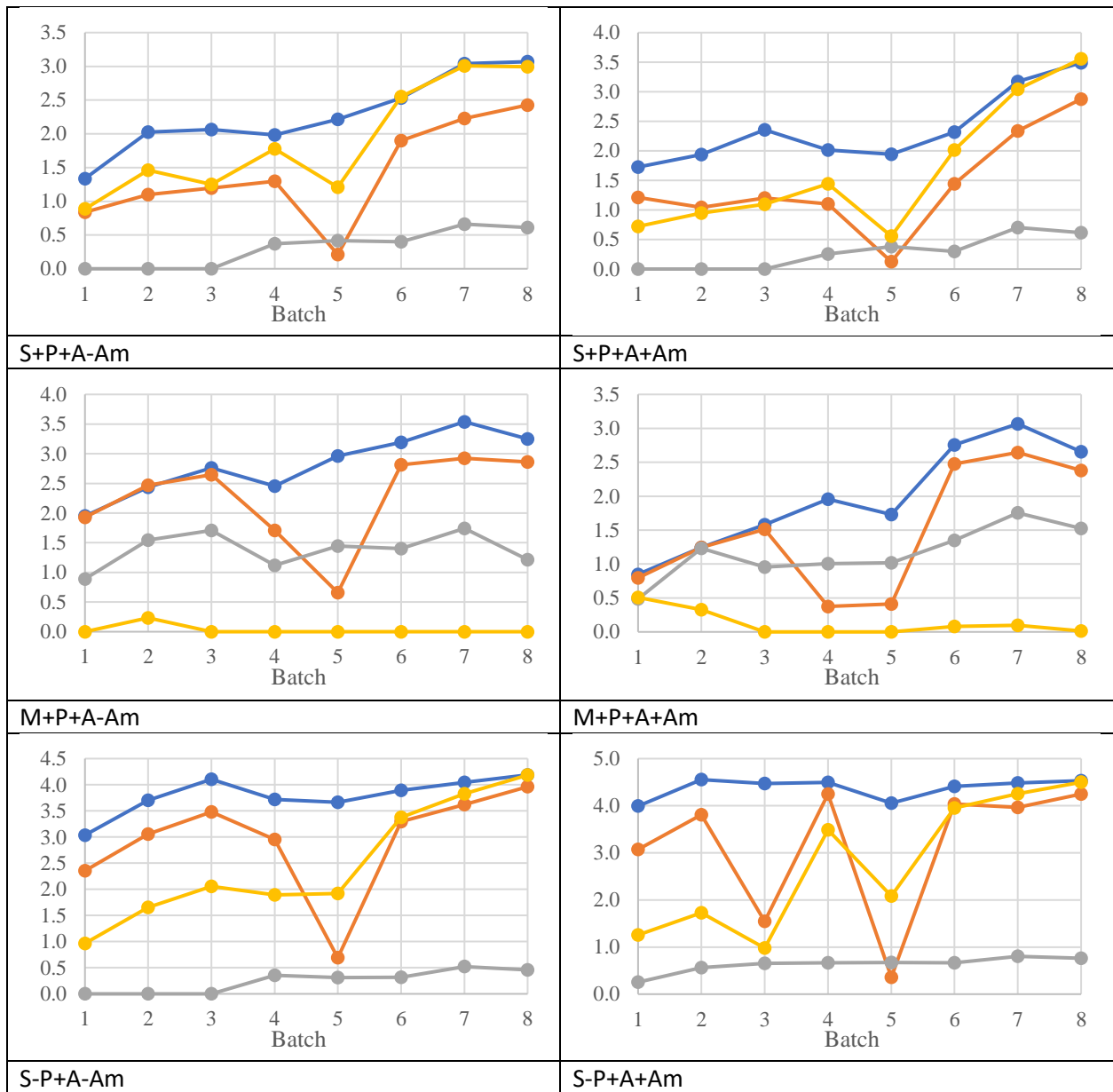
ESI 7. Micropollutants removal (%) per sampling batch upon the single effect of variables

(Mean±SE)

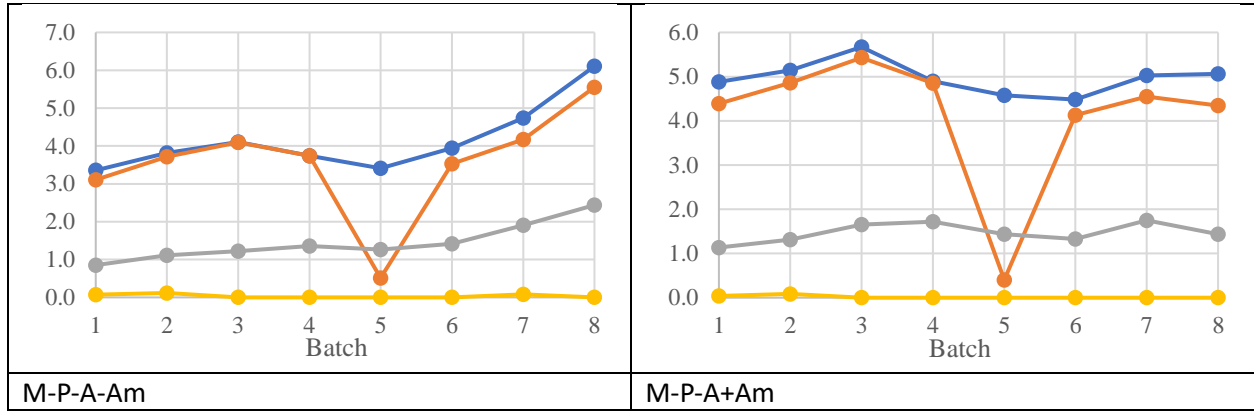
DCF								
Batch	Media*		Plant		Aeration*		Ammonium	
	S	M	+P	-P	+A	-A	+Am	-Am
1	84.61±2.09	97.45±1.26	91.65±2.6	90.41±3.29	87.92±3.24	94.14±2.11	90.05±3.02	92.01±2.88
2	74.26±3.15	96.91±0.84	85.04±4.66	86.12±5.04	82.93±4.97	88.24±4.54	85.83±4.66	85.33±5.05
3	77.79±3.81	100±0	89.74±4.08	88.05±5.73	85.62±5.92	92.17±3.41	89.26±4.14	88.53±5.71
4	65.45±6.59	99.55±0.42	85.8±5.41	79.21±9.71	76.95±9.85	88.05±4.55	79.32±9.32	85.69±6.07
5	82.86±5.49	100±0	95.06±3.03	87.80±6.18	85.75±6.27	97.1±1.62	91.28±5.02	91.58±5.1
6	54.54±7.97	99.73±0.21	82.01±7.43	72.26±12.14	68.61±12.45	85.66±5.8	75.61±10.83	78.66±9.57
7	43.44±6.35	98.24±0.84	73.86±9.25	67.83±12.94	64.37±13.59	77.32±7.67	69.27±11.84	72.42±10.7
8	40.73±8.32	99.36±0.44	75.07±10.28	67.83±12.94	61.3±14.95	78.8±8.34	68.33±13.35	71.76±11.66
SMBTR								
Batch	Media*		Plant*		Aeration		Ammonium	
	S	M	+P	-P	+A	-A	+Am	-Am
1	58.73±10.49	26.20±12.14	62.13±7.03	22.8±13.16	36.15±12.03	48.79±13.3	38.19±15.5	46.75±9.35
2	26.67±16.74	20.5±11.58	49.78±5.09	-2.61±13.98	28.28±12.16	18.89±16.22	28.76±13.82	18.41±14.79
3	40.58±11.74	2.57±14	44.56±7.85	-1.41±14.98	13±14.1	30.14±14.74	12.69±16.78	30.46±11.54
4	37.33±9.99	14.62±9.89	45.60±5.41	6.36±9.76	223±10.72	29.94±10.73	17.27±12.4	34.69±7.68
5	38.84±8.67	18.79±9.88	48.85±4.87	8.78±8.06	21.25±9.99	36.38±9.34	25.62±11.76	32±7.89
6	35.41±9.09	14.46±8.27	44.12±5.15	5.74±7.12	15.17±8.32	34.69±9.27	21.62±10.65	28.24±8.12
7	23.23±6.84	0.9±7.51	28.12±4.6	-3.99±6.64	6.96±7.52	17.16±8.65	8.08±9.33	16.05±6.88
8	19.37±8.5	-3.71±10.77	27.97±6.22	-12.3±8.47	4.86±7.15	10.8±13.14	8.66±10.19	7±11.05
MTP								
Batch	Media*		Plant		Aeration		Ammonium	
	S	M	+P	-P	+A	-A	+Am	-Am
1	98.4±1.6	48±5.57	73.81±11.15	72.59±9.52	76.46±8.58	69.94±11.76	71.84±10.57	74.56±10.14
2	95.6±3.53	31.59±3.95	62.73±14.24	64.46±10.85	63.07±12.08	64.11±13.22	59.83±12.44	67.35±12.72
3	95.6±4.4	16.96±6.87	56.31±17.47	56.25±14.25	57.67±14.13	54.89±17.55	52.85±16.03	59.71±15.75
4	81.18±4.72	13.27±5.8	54.12±13.07	40.32±14.17	47.12±10.91	47.32±16.31	41.27±15	53.18±12.25
5	85.17±2.95	38.39±2.72	65.02±8.89	58.54±9.5	58.21±8.51	65.35±9.82	60.62±8.95	62.94±9.59
6	86.32±3.6	31.94±2.73	62.45±9.99	55.82±11.34	52.79±10	65.47±10.95	58.25±10.64	60±10.87
7	74.37±3.04	11.56±1.91	43.09±12.59	42.83±11.66	41±10.16	44.92±13.79	41.08±11.98	44.84±12.25
8	77.6±3.63	17.87±6.68	50.42±11.05	45.04±13.72	47.95±8.62	47.51±15.43	46.04±11.57	49.41±13.33
BPS								
Batch	Media*		Plant*		Aeration		Ammonium	
	S	M	+P	-P	+A	-A	+Am	-Am
1	69.64±5.88	42.26±8.96	69.2±5.72	42.7±9.25	55.57±9.12	56.33±9.22	52.53±10.91	59.37±6.79
2	64.29±7.37	33.26±9.38	62.73±6.12	34.81±10.86	47.49±10.85	50.05±9.63	44.22±12.12	53.33±7.63
3	68.31±6.3	20.16±10.87	59.08±7.95	29.38±14.04	44.02±12.52	44.44±12.91	41.4±14.72	47.07±10.22
4	58.16±8.57	56.2±12.86	63.81±7.49	50.56±13.06	67.9±10.74	46.46±9.55	50.93±12.96	63.44±7.74
5	96.44±1.68	88.7±2.3	94.6±1.53	90.54±2.98	88.84±2.58	96.3±1.32	92.53±2.82	92.61±2.11
6	57.57±7.8	35.43±6.38	60.1±4.63	32.94±7.91	37.95±7.79	55.05±7.42	42.24±9.38	50.76±6.59
7	48.63±5.89	26.56±5.64	48.33±4.73	26.85±6.78	33.23±6.66	41.95±7.18	32.72±7.94	42.46±5.61
8	44.75±6.96	27.31±6.05	47.88±5.22	24.17±6.28	31.46±6.26	40.6±7.85	31.08±7.66	40.98±6.42

note: * indicates the significance of the single effect.

ESI 8. Timeline of the effluent concentrations (orange line - BPS, grey line – MTP, yellow line – DCF; blue line – 5MBTR; y-axis shows concentration [mg/L])



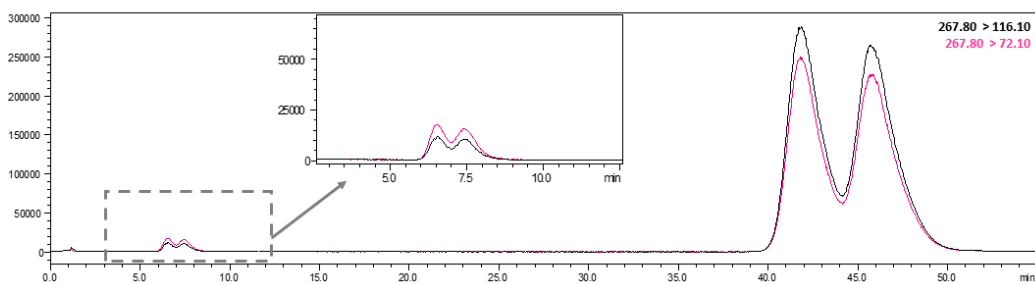




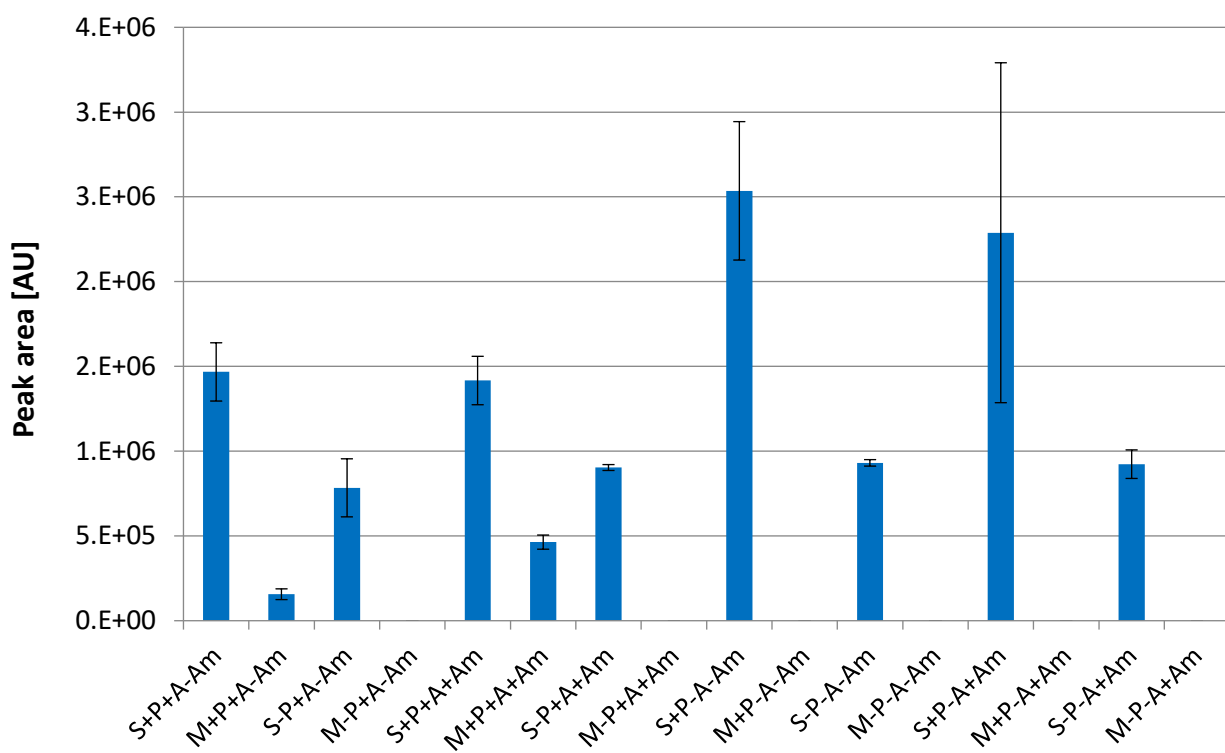
ESI 9. Resilience descriptors for the studied treatment based on the removal efficiency of DCF, 5MBTR, MTP and BPS (the two lowest values for each measure of resilience are given in bold)

	Differences in removal		Variance
	Min and max value	Start and end value	
S+P+A-Am	41.3	37.7	224.3
M+P+A-Am	33.4	17.7	156.0
S-P+A-Am	47.4	38.4	295.4
M-P+A-Am	36.9	18.3	294.8
S+P+A+Am	48.7	41.3	307.1
M+P+A+Am	42.4	34.8	276.0
S-P+A+Am	50.8	32.0	474.8
M-P+A+Am	51.4	9.7	528.8
S+P-A-Am	30.9	19.5	121.5
M+P-A-Am	34.8	3.7	181.0
S-P-A-Am	64.6	33.2	708.2
M-P-A-Am	58.7	44.0	455.0
S+P-A+Am	32.7	18.2	113.2
M+P-A+Am	42.0	26.5	296.1
S-P-A+Am	47.2	37.6	284.6
M-P-A+Am	50.5	5.3	376.7

ESI 10. Identity confirmation for metoprolol acid



ESI 11. Peak areas of metoprolol acid



ESI 12. Abiotic removal of MTPA

Material	Temperature	Removal, %
Sand	4 °C	1
	20 °C	1
MnOx	4 °C	30
	20 °C	50

References

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