Supplementary Information

Table S1 Occurrence of PAEs detected in natural water.

Environment	Sampling zone	The number of PAE detected	Concentration of PAEs in water (mg/L)	Reference
River	Changjiang River estuary, China	16	0.180–3.42	(Zhang et al., 2018)
	Spanish coast	6	0.060–2.28	(Concha-Grana et al., 2021)
	Yangtze River delta, China	9	0.002–0.006	(Zhu et al., 2022)
Seawater	East China sea	16	0.002–0.032	(Zhang et al., 2020)
	Mediterranean Sea	8	0.075–1.21	(Paluselli et al., 2018)
	Tunisian Marine	6	≤ 0.811	(Jebara et al., 2021)
	Northern South China sea	15	0.046–7.80	(Cao et al., 2022)
Influent wastewater	Seventeen municipal wastewater treatment plants, Austria	6	0.003–0.034	(Clara et al., 2010)
	Three wastewater treatment plants in Qingdao, China	16	0.134–0.186	(Wu et al., 2018)
	Eleven municipal wastewater treatment plants, Poland	8	≤ 0.596	(Kotowska et al., 2020)

Table S2 Comparison of price of biochar and activated carbon.

Materials	Price	Reference
Biochar	$246 per ton	(Ahmad et al., 2012)
	$350–$1200 per ton	(Thompson et al., 2016)
	$51–$381 per ton	(Huggins et al., 2016)
	$534–$1057 per ton	(Haeldermans et al., 2020)
Activated carbon	$1500 per ton	(Ahmad et al., 2012)
	$1100–$1700 per ton	(Thompson et al., 2016)
	$800–$2500 per ton	(Huggins et al., 2016)
	$3124 per ton	(Shi et al., 2019)

Table S3 Physic-chemical properties of the biochars, AC, and GR.

Samples [α]	Yield (%)	pH	Ash (%)	Elemental content (%)				H/C	O/C	(O+N)/C	S_{BET} [β]	S_{micro}	S_{meso}
				C	H	O	N				(m^2/g)		
SDB	44.3	8.81±0.11	23.5±0.24	89.1	3.72	5.48	1.67	0.501	0.046	0.062	11.1	2.72	6.64
RHB	43.2	9.54±0.02	31.4±0.12	80.3	3.44	15.8	0.47	0.514	0.148	0.153	48.4	4.73	33.1
CSB	33.4	6.89±0.04	23.3±0.27	78.6	4.15	16.1	1.13	0.633	0.154	0.166	19.2	3.24	11.6
WSB	40.0	9.68±0.10	13.6±0.12	82.6	3.43	13.2	0.73	0.498	0.120	0.128	28.7	7.25	19.2
RSB	43.8	9.72±0.04	30.7±0.43	74.7	3.78	20.7	0.86	0.608	0.208	0.218	36.5	15.9	10.2
GRB	36.6	9.59±0.01	10.9±0.03	86.4	2.65	10.8	0.14	0.368	0.094	0.095	49.6	30.6	36.7
AC	/	9.11±0.03	10.3±0.01	95.9	0.99	2.86	0.22	0.124	0.022	0.024	799	935	78.0
GR	/	5.19±0.17	0.84±0.01	99.0	0.53	0.21	0.30	0.064	0.002	0.004	35.1	35.8	24.1

Notes: α) SDB, RHB, CSB, WSB, RSB, and GRB are the biochars derived from saw dust, rice husk, corn straw, wheat straw, rice straw and giant reed respectively. AC: coal based activated carbon; GR: graphene. β) S_{BET} (m^2/g) is surface area calculated by a Brunauer-Emmett-Teller model from N_2 adsorption isotherm. S_{mico} and S_{meso} are micropore and mesopore surface area.

Table S4 Surface functional groups and elemental composition of the biochars from XPS analysis.

Samples [α)]	Total C (%)	C-C (%)	C-O (%)	C=O (%)	O=C-O (%)	O-containing group (%)	O (%)	N (%)	surface O/C	surface (O+N)/C	$B_{(O+N)/C}$ /$S_{(O+N)/C}$ [β)]
SDB	82.5	77.6	14.9	5.27	2.18	22.4	13.0	4.50	0.118	0.165	0.377
RHB	79.5	76.3	16.2	5.37	2.18	23.7	18.9	1.66	0.178	0.196	0.781
CSB	81.1	76.1	17.2	5.05	1.60	23.9	17.4	3.56	0.161	0.198	0.838
WSB	85.1	82.0	12.6	3.88	1.56	18.0	13.4	1.48	0.118	0.133	0.960
RSB	78.3	75.4	16.5	5.39	2.95	24.8	19.9	2.79	0.190	0.221	0.985
GRB	88.4	80.0	12.5	4.59	2.93	20.0	11.0	1.59	0.093	0.108	0.878

Notes: α) SDB, RHB, CSB, WSB, RSB, and GRB are the biochars derived from saw dust, rice husk, corn straw, wheat straw, rice straw and giant reed, respectively. β) $B_{(O+N)/C}$ /$S_{(O+N)/C}$ is the ratio of bulk polarity (calculated by data from elemental analysis) to surface polarity (calculated by data from XPS analysis).

Table S5 Parameters for DEP adsorption using Pseudo-first-order model, Pseudo-second-order model and Intraparticle diffusion (IPD) model.

Samples [α]	$Q_{e,exp}$ [β]	Pseudo-first-order model [γ]			Pseudo-second order model [δ]			Intraparticle diffusion (IPD) model [ε]					
								Stage I			StageII		
		Q_1 (mg/g)	k_1 (h^{-1})	R_{adj}^2	Q_2 (mg/g)	k_2 (g/mg/h)	R_{adj}^2	k_3^1 (mg/g/$h^{0.5}$)	b^1 (mg/g)	R_{adj}^2	k_3^2 (mg/g/$h^{0.5}$)	b^2 (mg/g)	R_{adj}^2
SDB	1.56	1.63	0.009	0.988	1.67	0.035	0.991	0.13	0.11	0.997	1.01	0.15	0.804
RHB	3.65	3.54	0.018	0.922	3.82	0.017	0.997	0.80	0.20	0.983	3.18	0.13	0.737
CSB	0.61	0.58	0.030	0.765	0.65	0.096	0.998	0.26	0.03	0.994	0.59	0.01	0.347
WSB	2.80	2.71	0.016	0.864	3.03	0.016	0.991	0.52	0.15	0.988	2.13	0.18	0.828
RSB	4.60	4.39	0.021	0.793	4.92	0.008	0.995	1.36	0.22	0.993	4.10	0.13	0.804
GRB	6.23	6.32	0.013	0.989	6.46	0.007	0.992	0.08	0.43	0.997	5.55	0.18	0.841
AC	224	221	1.150	0.904	226	0.032	0.998	/	/	/	/	/	/
GR	8.32	8.21	0.896	0.990	8.44	0.361	0.998	/	/	/	/	/	/

Notes: α) SDB, RHB, CSB, WSB, RSB, and GRB are the biochars derived from saw dust, rice husk, corn straw, wheat straw, rice straw and giant reed, respectively. AC: coal based activated carbon; GR: graphene. β) $Q_{e,exp}$ is the adsorption capacity calculated at equilibrium. γ) Q_1 is the adsorption capacity calculated by Pseudo-first-order model, mg/g. k_1 is the rate constant of PF-order model, h^{-1}. R_{adj}^2 is the adjusted coefficient of determination and it is influenced by both the number of data points (m) and the number of fitting parameters (p). $R_{adj}^2 = (1-(m-1)(1-R^2))/(m-p-1)$. δ) Q_2 is the adsorption capacity calculated by Pseudo-second order model, mg/g. k_2 is the rate constant of Pseudo-second order model fitted the adsorption of DEP, g/mg/h. ε) k_3^1 and k_3^2 (mg/g/$h^{0.5}$) are the fitted rate constants of stage I and stage II of IPD model, respectively; b^1, b^2 (mg/g) are the fitted intercepts of IPD model, respectively.

Table S6 Parameters of DEP sorption isotherm on different biochars fitted by Langmuir and Freundlich model.

Samples α)	Langmuir model β)			Freundlich model γ)			log K_d δ)		log K_{oc}		Log K_{oc}/log K_{ow}
	Q_m (mg/g)	K_L (L/mg)	R_{adj}^2	K_F ((mg/g)·(mg/L)$^{-N}$)	N η)	R_{adj}^2	(C_e=0.01S_w)	(C_e=0.01S_w)	(C_e=0.1S_w)	(C_e=1S_w)	(C_e=0.01S_w)
SDB	18.4	0.01	0.981	0.82	0.52	0.994	2.42	2.59	3.11	3.63	1.08
RHB	11.4	0.03	0.945	0.96	0.50	0.991	2.47	2.73	3.23	3.73	1.14
CSB	5.08	0.01	0.995	0.07	0.75	0.997	1.60	1.82	2.57	3.32	0.76
WSB	10.3	0.03	0.973	0.17	0.79	0.989	2.02	2.17	2.96	3.75	0.91
RSB	31.5	0.02	0.978	1.30	0.62	0.996	2.72	3.01	3.63	4.25	1.26
GRB	46.0	0.01	0.998	1.13	0.71	0.992	2.75	2.86	3.57	4.27	1.20
AC	261	6.96	0.962	186	0.10	0.849	4.34	4.40	4.50	4.60	1.84
GR	10.9	0.37	0.935	4.42	0.22	0.964	2.84	2.85	3.08	3.30	1.19

Notes: α) SDB, RHB, CSB, WSB, RSB, and GRB are the biochars derived from saw dust, rice husk, corn straw, wheat straw, rice straw and giant reed, respectively. AC: coal based activated carbon; GR: graphene. β) Q_m: the maximum sorption capacity, mg/g. K_L: the sorption coefficient, L/mg. R_{adj}^2: the adjusted coefficient of determination, which is influenced by both the number of data points and the number of fitting parameters, $R_{adj}^2 = (1-(m-1)(1-R^2))/(m-p-1)$. γ) K_F: the sorption coefficient of Frendlich model, (mg/g)·(mg/L)$^{-N}$. η) N: the nonlinearity index related to the surface site heterogeneity of the sorbent. δ) K_d: the adsorption coefficients fitted by Langmuir model, L/kg. C_e=0.01 S_w, S_w: the solubility of DEP in water measured at 25℃ (1080 mg/L), K_{oc}: K_d normalized with organic carbon in biochar.

Table S7 Adsorption thermodynamic parameters of DEP on the biochars.

Samples[α)]	C_0 (mg/L)	ΔH^{0} [β)] (kJ/mol)	ΔG^0 (kJ/mol)			ΔS^0 (J/mol/K)		
			288K	298K	308K	288K	298K	308K
SDB	2	–17.32	–19.98	–16.52	–18.63	9.23	–2.69	4.24
	5	–17.29				9.33	–2.58	4.34
	10	–10.81				31.83	19.16	25.38
	20	–13.09				23.91	11.51	17.97
	30	–9.66				35.82	23.02	29.11
	40	–7.35				43.85	30.77	36.61
	50	–7.34				43.88	30.80	36.64
	60	–8.20				40.89	27.92	33.85
	80	–9.04				37.98	25.10	31.12
	100	–8.47				39.96	27.01	32.97
RHB	2	–20.45	–20.44	–21.43	–24.10	–0.03	3.28	11.86
	5	–17.81				9.13	12.14	20.43
	10	–13.30				24.79	27.27	35.07
	20	–10.80				33.47	35.66	43.19
	30	–8.19				42.53	44.42	51.66
	40	–8.83				40.31	42.27	49.59
	50	–6.96				46.81	48.55	55.66
	60	–5.48				51.94	53.51	60.46
	80	–6.22				49.37	51.03	58.06
	100	–6.73				47.60	49.32	56.41
CSB	2	–7.94	–17.05	–17.88	–17.39	31.62	33.34	30.67
	5	–5.44				40.30	41.73	38.79
	10	–4.47				43.67	44.99	41.94
	20	–3.64				46.55	47.77	44.63
	30	–3.21				48.04	49.21	46.03
	40	–2.92				49.05	50.19	46.97
	50	–2.86				49.26	50.39	47.17
	60	–2.60				50.16	51.26	48.01
	80	–1.93				52.49	53.51	50.18
	100	–2.58				50.23	51.33	48.07
WSB	2	–19.79	–21.00	–21.79	–21.79	4.19	6.71	6.51
	5	–24.09				–10.74	–7.72	–7.46
	10	–19.96				3.60	6.14	5.95
	20	–15.53				18.99	21.00	20.34
	30	–13.26				26.87	28.62	27.71

	40	–10.24				37.35	38.75	37.51
	50	–8.53				43.29	44.49	43.06
	60	–8.73				42.60	43.82	42.42
	80	–7.45				47.04	48.12	46.57
	100	–6.88				49.02	50.03	48.42
RSB	2	–20.85	–19.59	–20.21	–20.50	–4.39	–2.15	–1.12
	5	–19.80				–0.74	1.38	2.28
	10	–20.04				–1.58	0.57	1.51
	20	–13.15				22.35	23.69	23.88
	30	–10.07				33.04	34.03	33.88
	40	–9.59				34.71	35.64	35.43
	50	–8.41				38.81	39.60	39.27
	60	–7.55				41.79	42.48	42.06
	80	–7.36				42.45	43.12	42.67
	100	–7.66				41.41	42.11	41.70
GRB	2	–32.39	–17.23	–19.96	–21.04	–52.64	–41.71	–36.84
	5	–32.31				–52.37	–41.44	–36.58
	10	–19.22				–6.91	2.48	5.92
	20	–14.27				10.27	19.09	21.99
	30	–9.91				25.41	33.72	36.14
	40	–9.66				26.28	34.56	36.95
	50	–8.63				29.86	38.02	40.30
	60	–9.08				28.29	36.51	38.84
	80	–9.81				25.76	34.06	36.47
	100	–9.92				25.38	33.69	36.11

Notes: α) SDB, RHB, CSB, WSB, RSB, and GRB are the biochars derived from saw dust, rice husk, corn straw, wheat straw, rice straw and giant reed, respectively. β) ΔG^0 is the Gibbs energy change, $\Delta G^0 = -RT \ln K$, kJ/mol. ΔH^0 is the enthalpy change, which calculated from the respective slope of the plot of ln $1/C_e$ (C_e = 2, 5, 10, 20, 30, 40, 50, 60, 80, 100 mg/L) against $1/T$ theoretically yields straight lines, kJ/mol. ΔS^0 is the entropy change, J/mol/K.

Table S8 Parameters of first-order two-compartment kinetic model based on the desorption kinetic curves of DEP from the sorbents.

Samples [α]	F_{fast} [β]	F_{slow}	k_{fast} [γ] (h^{-1})	k_{slow} ($10^{-4}\times h^{-1}$)	R_{adj}^2 [δ]	Total desorption rate (%)
SDB	0.07	0.93	4.35	0.76	0.987	8.07
RHB	0.10	0.91	6.76	0.68	0.989	11.3
CSB	0.24	0.76	3.32	4.69	0.985	30.9
WSB	0.08	0.92	8.56	0.32	0.997	8.57
RSB	0.03	0.97	7.34	0.22	0.989	3.78
GRB	0.04	0.96	3.95	0.36	0.993	4.58
AC	0.05	0.95	1.43	1.61	0.994	5.29
GR	0.02	0.98	6.75	0.11	0.991	1.93

Notes: α) SDB, RHB, CSB, WSB, RSB, and GRB are the biochars derived from saw dust, rice husk, corn straw, wheat straw, rice straw and giant reed, respectively. AC: coal based activated carbon; GR: graphene. β) F_{fast} is the distribution ratio of fast desorption. F_{slow} is the distribution ratio of slow desorption. γ) k_{fast} is the rate constant of the fast desorption process, h^{-1}. k_{slow} is the rate constant of the slow desorption process, $10^{-4}\times h^{-1}$. δ) R_{adj}^2 is the adjusted coefficient of determination and it is influenced by both the number of data points (m) and the number of fitting parameters (p). $R_{adj}^2 = (1-(m-1)\ (1-R^2))/(m-p-1)$.

Table S9 Dual model fitting results of DEP sorption on biochars.

Samples [α]	Q_{am} [β] (mg/g)	K_a (L/mg)	K_p ((mg/g)/(mg/L))	R_{adj}^2	C_e= 0.01 S_w			C_e= 0.1 S_w			C_e= S_w		
					Q_{ad} [γ] (mg/g)	Q_p (mg/g)	*Ratio*	Q_{ad} (mg/g)	Q_p (mg/g)	*Ratio*	Q_{ad} (mg/g)	Q_p (mg/g)	*Ratio*
SDB	0.62	0.48	0.06	0.992	0.52	0.68	0.76	0.60	6.76	0.09	0.61	67.6	0.01
RHB	2.76	0.55	0.08	0.993	2.37	0.86	2.74	2.72	8.65	0.31	2.76	86.5	0.03
CSB	0.86	0.04	0.02	0.995	0.25	0.17	1.45	0.69	1.71	0.40	0.84	17.1	0.05
WSB	2.98	0.25	0.07	0.990	2.19	0.76	2.88	2.88	7.60	0.38	2.97	76.0	0.04
RSB	4.75	0.33	0.20	0.997	3.70	2.17	1.71	4.62	21.7	0.21	4.74	217	0.02
GRB	11.4	0.08	0.18	0.998	5.10	1.93	2.64	10.1	19.3	0.52	11.2	193	0.06
AC	298	4.07	1.80	0.914	292	19.5	15.0	298	195	1.53	298	1946	0.15
GR	8.53	0.92	0.04	0.981	7.75	0.43	18.2	8.44	4.25	1.99	8.52	42.5	0.20

Notes: α) SDB, RHB, CSB, WSB, RSB, and GRB are the biochars derived from saw dust, rice husk, corn straw, wheat straw, rice straw and giant reed, respectively. AC: coal based activated carbon; GR: graphene. β) Q_{am} is maximum adsorption capacity, mg/g. K_a is affinity coefficient, L/mg. K_p is the partitioning coefficient, (mg/g)/(mg/L). R_{adj}^2 is the adjusted coefficient of determination and it is influenced by both the number of data points (m) and the number of fitting parameters (p). $R_{adj}^2 = (1-(m-1)\ (1-R^2))/(m-p-1)$. γ) Q_{am} is the adsorption contribution for the total sorption, mg/g. Q_p is the partition contribution for the total sorption, mg/g. *Ratio*= Q_{am} / Q_p.

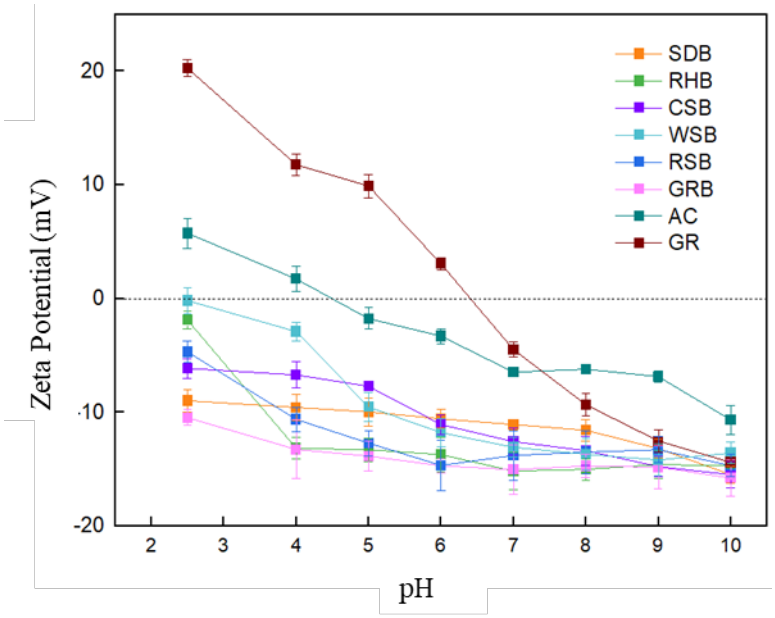

Fig. S1 Zeta potential (ξ) of biochars, AC, and GR at different pH. SDB, RHB, CSB, WSB, RSB, and GRB are the biochars derived from saw dust, rice husk, corn straw, wheat straw, rice straw and giant reed, respectively. AC: coal based activated carbon; GR: graphene.

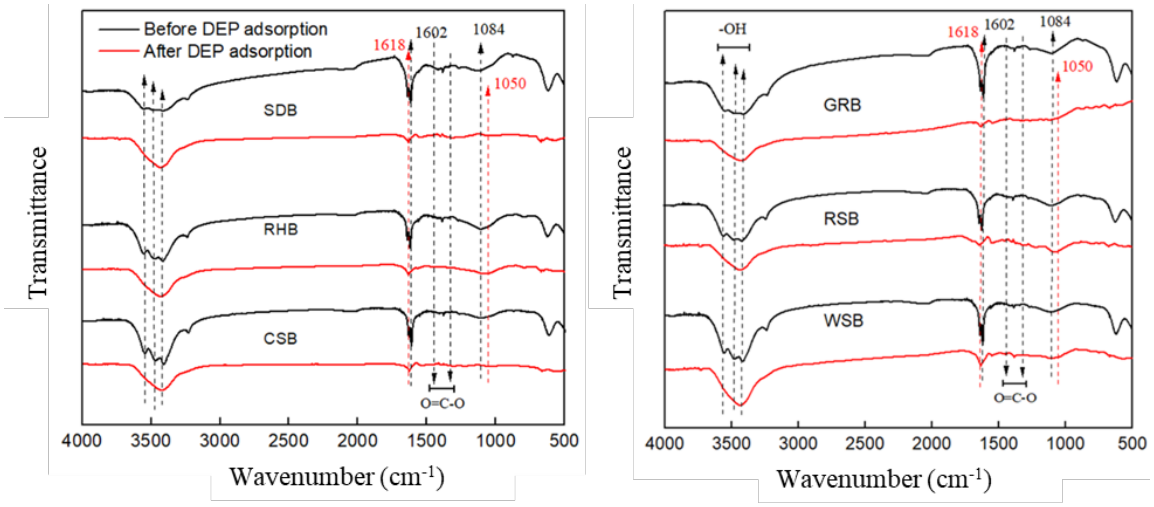

Fig. S2 FTIR spectra of biochars before and after DEP adsorption. SDB, RHB, CSB, WSB, RSB, and GRB are the biochars derived from saw dust, rice husk, corn straw, wheat straw, rice straw and giant reed, respectively.

References

Ahmad M, Lee S S, Dou X, Mohan D, Sung J K, Yang J E, Ok Y S (2012). Effects of pyrolysis temperature on soybean stover- and peanut shell-derived biochar properties and TCE adsorption in water. Bioresource Technology, 118: 536–544

Cao Y, Li J, Wu R, Lin H, Lao J Y, Ruan Y, Zhang K, Wu J, Leung K M Y, Lam P K S (2022). Phthalate esters in seawater and sediment of the northern South China Sea: Occurrence, distribution, and ecological risks. Science of the Total Environment, 811: 151412

Clara M, Windhofer G, Hartl W, Braun K, Simon M, Gans O, Scheffknecht C, Chovanec A (2010). Occurrence of phthalates in surface runoff, untreated and treated wastewater and fate during wastewater treatment. Chemosphere, 78(9): 1078–1084

Concha-Graña E, Moscoso-Pérez C, Fernández-González V, López-Mahía P, Gago J, León V M, Muniategui-Lorenzo S (2021). Phthalates, organotin compounds and per-polyfluoroalkyl substances in semiconfined areas of the Spanish coast: Occurrence, sources and risk assessment. Science of the Total Environment, 780: 146450

Haeldermans T, Campion L, Kuppens T, Vanreppelen K, Cuypers A, Schreurs S (2020). A comparative techno-economic assessment of biochar production from different residue streams using conventional and microwave pyrolysis. Bioresource Technology, 318: 124083

Huggins T M, Haeger A, Biffinger J C, Ren Z J (2016). Granular biochar compared with activated carbon for wastewater treatment and resource recovery. Water Research, 94(1): 225–232

Jebara A, Albergamo A, Rando R, Potortì A G, Lo Turco V, Mansour H B, Di Bella G (2021). Phthalates and non-phthalate plasticizers in Tunisian marine samples: Occurrence, spatial distribution and seasonal variation. Marine Pollution Bulletin, 163: 111967

Kotowska U, Kapelewska J, Sawczuk R (2020). Occurrence, removal, and environmental risk of phthalates in wastewaters, landfill leachates, and groundwater in Poland. Environmental Pollution, 267: 115643

Paluselli A, Aminot Y, Galgani F, Net S, Sempéré R (2018). Occurrence of phthalate acid esters (PAEs) in the northwestern Mediterranean Sea and the Rhone River. Progress in Oceanography, 163: 221–231

Shi J, Han Y, Xu C, Han H (2019). Enhanced biodegradation of coal gasification wastewater with anaerobic biofilm on polyurethane (PU), powdered activated carbon (PAC), and biochar. Bioresource Technology, 289: 121487

Thompson K A, Shimabuku K K, Kearns J P, Knappe D R U, Summers R S, Cook S M (2016). Environmental comparison of biochar and activated carbon for tertiary wastewater treatment. Environmental Science & Technology, 50(20): 11253–11262

Wu J, Ma T, Zhou Z, Yu N, He Z, Li B, Shi Y, Ma D (2018). Occurrence and fate of phthalate esters in wastewater treatment plants in Qingdao, China. Human and Ecological Risk Assessment, 25(6): 1547–1563

Zhang Z M, Yang G P, Zhang H H, Shi X Z, Zou Y W, Zhang J (2020). Phthalic acid esters in the sea-surface microlayer, seawater and sediments of the East China Sea: Spatiotemporal variation and ecological risk assessment. Environmental Pollution, 259: 113802

Zhang Z M, Zhang H H, Zhang J, Wang Q W, Yang G P (2018). Occurrence, distribution, and ecological risks of phthalate esters in the seawater and sediment of Changjiang River Estuary and its adjacent area. Science of the Total Environment, 619–620: 93–102

Zhu Q, Xu L, Wang W, Liu W, Liao C, Jiang G (2022). Occurrence, spatial distribution and ecological risk assessment of phthalate esters in water, soil and sediment from Yangtze River Delta, China. Science of the Total Environment, 806(Pt 4): 150966