Supplementary Information For:

Rapid and efficient removal of phosphate by La-doped layered double hydroxide/biochar from aqueous solution

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Figure Captions

Fig. S1 XRD patterns of BC, La-MgAl-LDH, La- MgAl-LDH/BC, P-loaded La- MgAl-LDH/BC.

Fig. S2 SEM images spectra of the La-MgAl-LDH/BC before adsorption.

Fig. S3 Pore size distributions of adsorbents.

Fig. S4 The phosphate removal ratio with initial phosphate concentration of 5 mg/L.

Fig. S5 SEM images and EDS spectra of the La-MgAl-LDH/BC before and after adsorption (a)-(d).

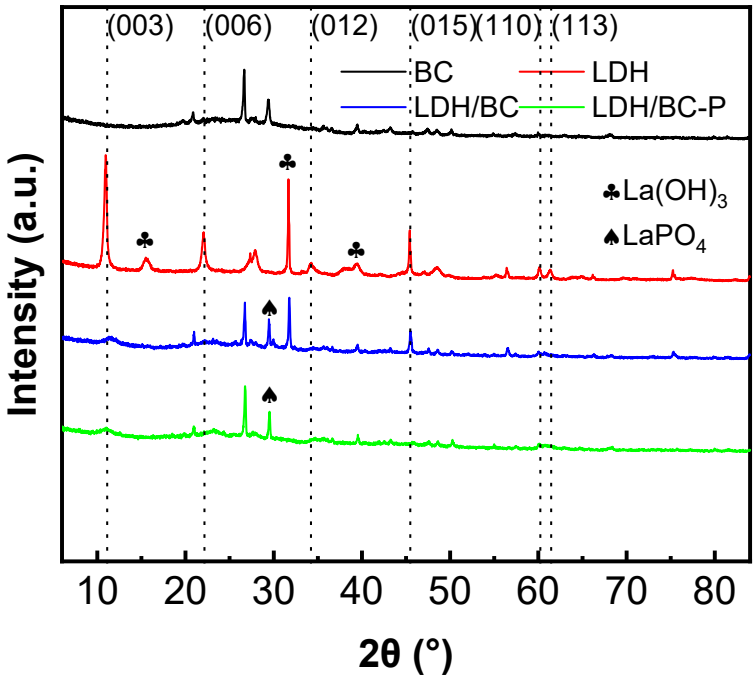
Fig. S6 FT-IR spectra of La-MgAl-LDH/BC and P-loaded La-MgAl-LDH/BC.

Fig. S7 XPS spectra of BC, La-MgAl-LDH, La-MgAl-LDH/BC, P-loaded La-MgAl-LDH/BC (a), P element XPS spectra (b), Cl element XPS spectra (c).

Fig. S8 Phosphate removal ratio of La-MgAl-LDH/BC in environmental water samples (a); recycle adsorption experiments of La-MgAl-LDH/BC for phosphate (b).

Fig. S9 The leaching of Mg, Al and La element of La-MgAl-LDH/BC after adsorption.

Table Captions



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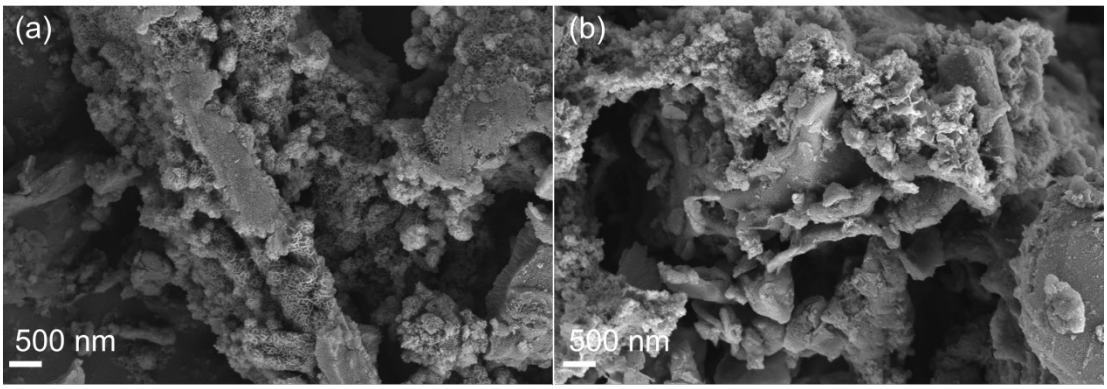

Fig. S2 SEM images spectra of the La-MgAl-LDH/BC before adsorption.

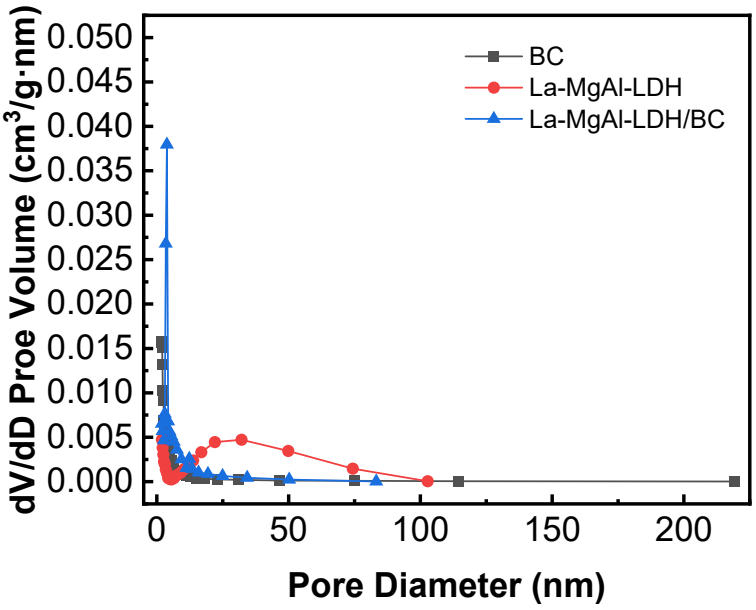

Fig. S3 Pore size distributions of adsorbents.

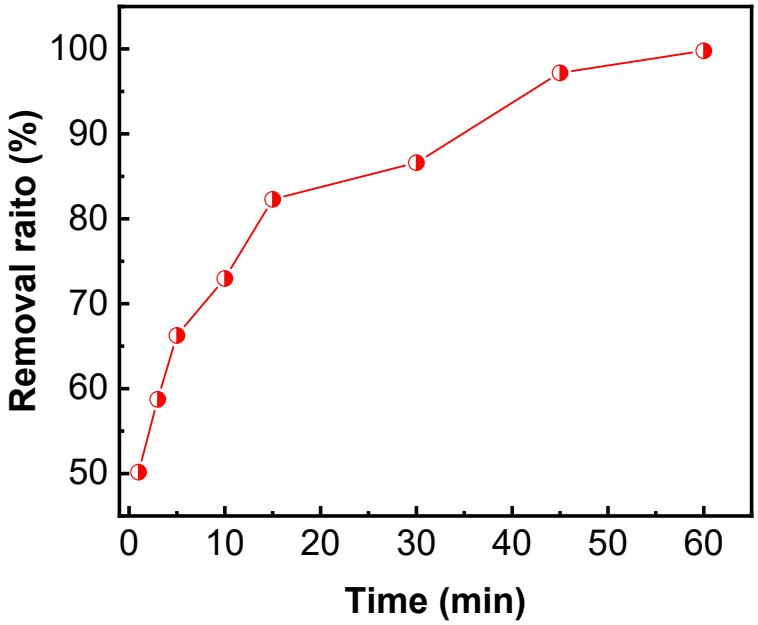

Fig. S4 The phosphate removal ratio with initial phosphate concentration of 5 mg/L (pH=6, T=25℃, adsorbent dosage 0.4 g/L, t=1 h).

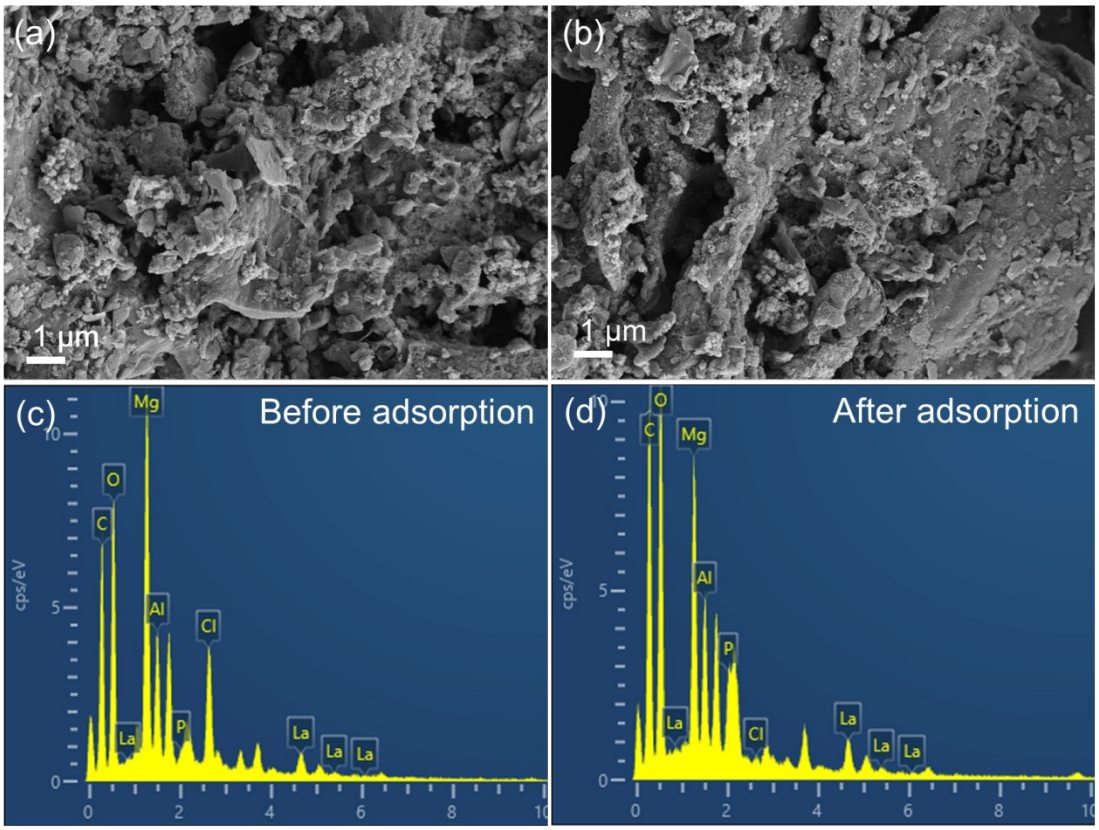

Fig. S5 SEM images and EDS spectra of the La-MgAl-LDH/BC before and after adsorption (a)-(d).

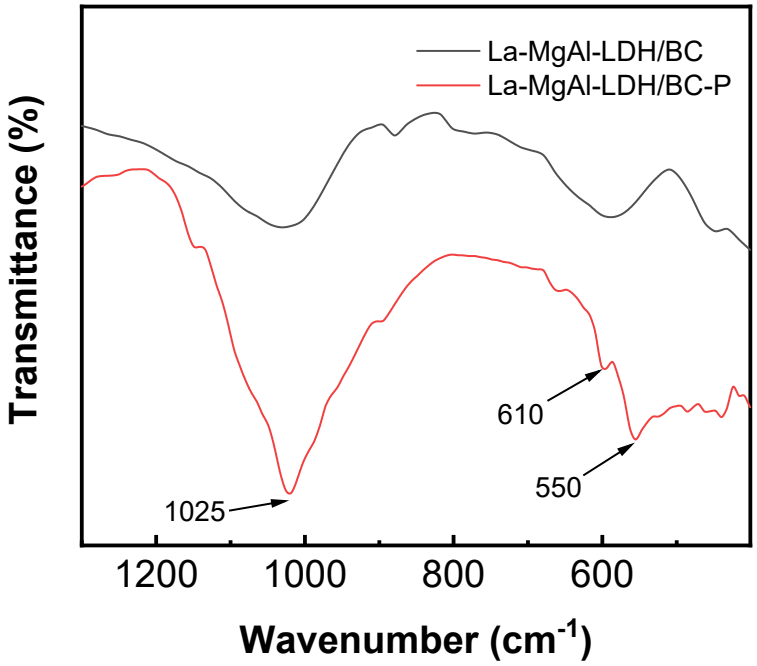

Fig. S6 FT-IR spectra of La-MgAl-LDH/BC and P-loaded La-MgAl-LDH/BC.

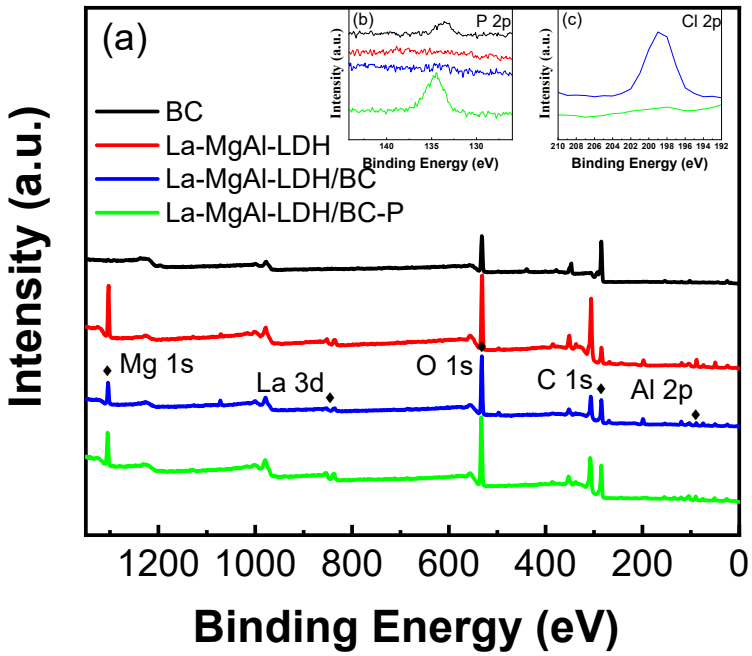

Fig. S7 XPS spectra of BC, La-MgAl-LDH, La-MgAl-LDH/BC, P-loaded La-MgAl-LDH/BC (a), P element XPS spectra (b), Cl element XPS spectra (c).

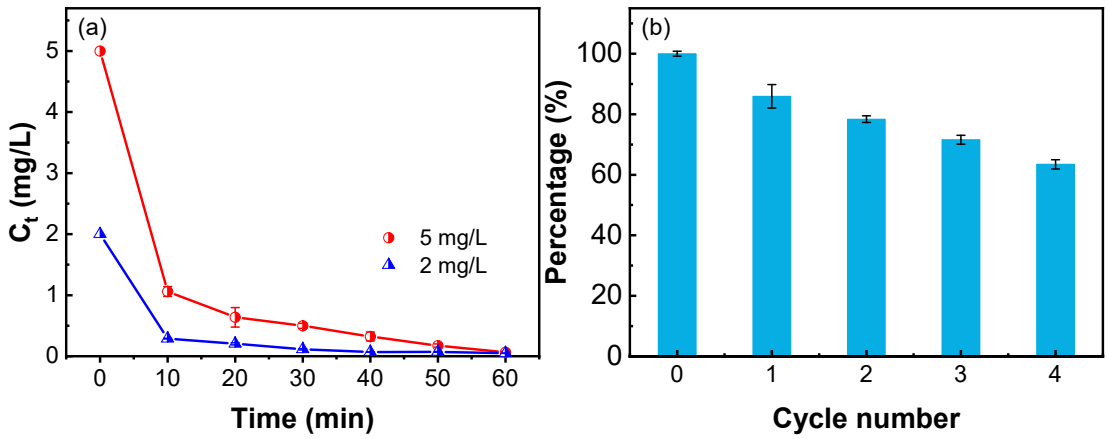

Fig. S8 Phosphate removal ratio of La-MgAl-LDH/BC in environmental water samples (a) (C_0=2 and 5 mg/L, pH=8.16, T=25℃, adsorbent dosage=1 g/L and t=1 h); recycle adsorption experiments of La-MgAl-LDH/BC for phosphate (b) (C_0= 10 mg/L, pH 6, T=25℃, adsorbent dosage=0.4 g/L, t=1 h and the La-LDH/BC was desorbed by 1 mol/L NaOH).

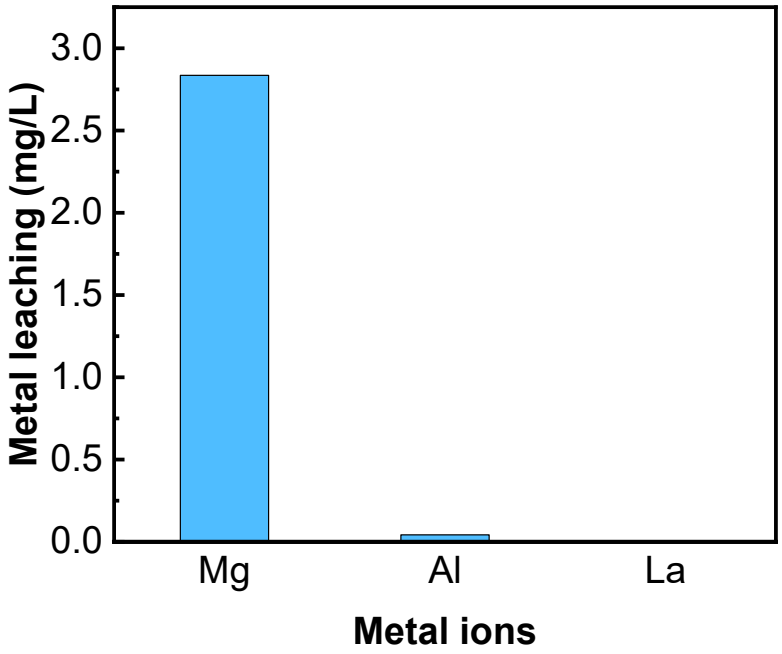

Fig. S9 The leaching of Mg, Al and La element of La-MgAl-LDH/BC after adsorption.

Table S1 Composition of La-MgAl-LDH composites.

LDH material	La:Al:Mg molar ratio	Dosage (g)		
		$LaCl_3 \cdot 7H_2O$	$AlCl_3$	$MgCl_2$
LDH	0:1:3	0	2.67	5.71
0.1La-LDH	0.1:0.9:3	0.74	2.40	5.71
0.2La-LDH	0.2:0.9:3	1.49	2.13	5.71
0.3La-LDH	0.3:0.9:3	2.23	1.87	5.71
0.5La-LDH	0.5:0.9:3	3.71	1.33	5.71

Table S2 Pore parameters of adsorbents.

Sample	SBET (m^2/g)	Smicro (m^2/g)	Sexternal (m^2/g)	Vpore (cm^3/g)	Dpore (nm)
BC	238.7	192.6	46.0	0.08	4.66
La-LDH	40.9		54.0	0.01	25.83
La-LDH/BC	177.4	111.8	65.6	0.05	5.93

Table S3 Fitting result of adsorption kinetics.

Kinetic model	Parameter	Initial concentration (mg/L)			
		5	10	20	50
Pseudo-first-order	k_1 (min^{-1})	0.52	0.56	0.26	0.13
	q^e (mg/g)	10.4	12.9	17.3	46.63
	R^2	0.62	0.82	0.89	0.99
Pseudo-second-order	k_2 (g/mg/min)	0.07	0.06	0.02	0.16
	qe (mg/g)	11.2	13.9	18.9	53.84
	R^2	0.97	0.94	0.95	0.99
Intraparticle- diffusion	K_{1pd} ($mg/g/min^{0.5}$)	1.73	3.74	4.10	12.45
	C (mg/g)	4.40	3.01	2.45	-5.22
	R^2	0.99	0.91	0.94	0.99
	K_{2pd} ($mg/g/min^{0.5}$)	1.21	1.03	2.46	11.31
	C (mg/g)	5.50	8.48	6.90	-2.81
	R^2	0.97	0.95	0.90	0.99
	K_{3pd} ($mg/g/min^{0.5}$)	0.37	0.53	0.80	1.64
	C (mg/g)	8.83	10.30	12.57	35.22
	R^2	0.99	0.85	0.91	0.95

Table S4 Parameters of phosphate adsorption isotherms.

Kinetic model	Parameter	Temperature (K)		
		288.15	298.15	308.15
Langmuir	q_{max} (mg/g)	212.1	230.5	249.3
	K_L (L/mg)	0.0045	0.0047	0.006
	R^2	0.94	0.95	0.95
Freundlich	K_F (g/mg/min)	8.39	9.17	12.03
	n	0.47	0.47	0.43
	R^2	0.86	0.94	0.95
Thermodynamic	ΔG^{θ} (kJ/mol)	-20.15	-20.96	-22.29
	ΔS^{θ} (J/mol/K)		10.71	
	ΔH^{θ} (kJ/mol)		106.8	

Table S5 Interlayer spacing changes of La-MgAl-LDH/BC before and after adsorption.

Sample	d_{003} (Å)	d_{110} (Å)	a (Å)	c (Å)	Interlayer spacing (Å)
Before adsorption	7.96	1.54	3.08	23.88	3.16
After adsorption	8.26	1.52	3.04	24.78	3.46

Table S6 Relative weight percentage of elements in XPS.

Atom	BC (%)	La-LDH (%)	La-LDH/BC (%)	La-LDH/BC-P (%)
C	72.72	31.49	43.34	45.49
O	23.71	46.14	37.87	38.00
Cl	0.05	0.83	1.87	0.09
La	0	0.75	0.51	0.78
Al	2.16	6.28	6.82	6.54
Mg	0.56	14.50	9.63	7.31
P	0.80	0	0.97	1.79

Table S7 Fitting parameters of C 1s and O 1s peak of La-MgAl-LDH/BC before and after phosphate adsorption.

Atom	Samples	Binding Energy	Peak	Percentage（%）
C 1s	Before adsorption	284.77	C-C	29.69
		285.89	C-O-C	11.03
		289.73	O-C=O	2.62
	After adsorption	284.67	C-C	23.52
		285.96	C-O-C	17.47
		289.94	O-C=O	4.51
O 1s	Before adsorption	531.70	M-O	9.82
		532.47	M-OH	17.42
		533.19	H2O	10.63
	After adsorption	532.13	M-O	10.95
		532.86	M-OH	15.24
		533.76	H2O	11.80