

Supplementary Materials

Potentially toxic metals in the tropical mangrove *Rhizophora apiculata*: A field-based biomonitoring study and phytoremediation potentials

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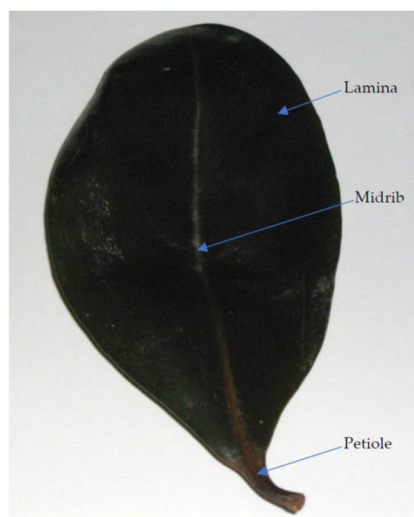


Figure S1. Parts of leaves (midrib plus petiole, and lamina) of mangrove (*Rhizophora apiculata*) investigated in the present study. .

Table S1. Sampling information in the mangrove areas of Sepang Besar River (1-4), and Lukut River (5-9) from the present study.

Site	Latitude	Longitude	Description of sampling site	Temp	Cond (µs/cm)	Salinity (ppt)
1	02° 36.653' N	101° 42.345'E	Prawns hatchery area.	27.99	34919	20.59
2	02° 36.102' N	101° 42.337'E	Mangrove area	28.01	36619	21.69
3	02° 36.042' N	101° 42.461'E	Mangrove area	27.87	36677	21.79
4	02° 35.933' N	101° 42.826'E	Mangrove area	28.36	40491	24.07
5	02° 34.978' N	101° 47.607'E	Mangrove area; nearby a construction site	29.89	33343	18.81
6	02° 34.979' N	101° 47.668'E	Mangrove area	29.83	28452	15.82
7	02° 34.847' N	101° 47.795'E	Mangrove area	29.40	29706	16.73
8	02° 34.853' N	101° 47.882'E	Mangrove area	29.73	33140	18.75
9	02° 34.737' N	101° 48.033'E	Mangrove area; boating activity; nearby construction	30.14	28093	15.50

Table S2. Heavy metals analysis recovery percentages of the certified reference materials (CRM).

CRM	Cu	Fe	Ni	Pb	Zn
NSC DC73319 Soil China	85.0%	NA	NA	99.8%	99.7%
MESS - 3 NRC	93.1%	NA	102%	116%	82.8%
TH-1 Sediment Canada	92.9%	95.6%	112%	100%	110%
SRM 1547	NA	106%	NA	NA	115%
IAEA Soil-5	91.3%	NA	103%	116%	94.8%

NA - data not available.

Table S3. Mean concentrations (mg/kg dry weight) of Zn in the leaf parts (lamina (L); midrib plus petiole (MP)) of *Rhizophora apiculata* and their habitat geochemical fraction sediments, with their bioconcentration factor (BCF) values in the mangrove of Sepang Besar River (1-4), and Lukut River (5-9) from the present study.

Site	Part	Plant	F1	F2	F3	F4	SUM	Total	BCF1	BCF2	BCF3	BCF4	BCF5
1	L	13.4	0.94	14.2	34.1	60.7	110	82.1	14.3	0.94	0.39	0.22	0.12
2	L	19.0	1.53	15.8	22.5	26.6	66.5	74.8	12.4	1.20	0.84	0.71	0.29
3	L	16.4	1.55	19.1	43.8	41.7	106	88.3	10.6	0.86	0.37	0.39	0.15
4	L	8.62	1.25	13.5	14.5	22.4	51.7	64.9	6.90	0.64	0.59	0.38	0.17
5	L	15.0	4.84	15.0	18.8	15.7	54.3	45.5	3.09	1.00	0.80	0.95	0.28
6	L	18.1	2.54	26.2	37.3	35.7	102	79.3	7.13	0.69	0.48	0.51	0.18
7	L	9.74	2.04	22.3	34.0	38.9	97.2	74.3	4.77	0.44	0.29	0.25	0.10
8	L	7.28	2.03	19.9	23.5	32.7	78.1	62.0	3.59	0.37	0.31	0.22	0.09
9	L	15.0	2.71	24.1	33.3	28.4	88.5	74.4	5.53	0.62	0.45	0.53	0.17
1	MP	9.99	0.94	14.2	34.1	60.7	110	82.1	10.6	0.70	0.29	0.16	0.09
2	MP	14.2	1.53	15.8	22.5	26.6	66.5	74.8	9.29	0.90	0.63	0.53	0.21
3	MP	6.08	1.55	19.1	43.8	41.7	106	88.3	3.92	0.32	0.14	0.15	0.06
4	MP	6.76	1.25	13.5	14.5	22.4	51.7	64.9	5.41	0.50	0.46	0.30	0.13
5	MP	12.8	4.84	15.0	18.8	15.7	54.3	45.5	2.65	0.86	0.68	0.82	0.24
6	MP	10.8	2.54	26.2	37.3	35.7	102	79.3	4.24	0.41	0.29	0.30	0.11
7	MP	8.36	2.04	22.3	34.0	38.9	97.2	74.29	4.10	0.38	0.25	0.22	0.09
8	MP	7.16	2.03	19.9	23.5	32.7	78.1	62.0	3.53	0.36	0.31	0.22	0.09
9	MP	8.72	2.71	24.1	33.3	28.4	88.5	74.4	3.22	0.36	0.26	0.31	0.10

Note: BCF1= leave/F1; BCF2= leave/F2; BCF3= leave/F3; BCF4= leave/F4; BCF5= leave/SUM; F1= easily, freely or exchangeable fraction; F2= acid-reducible fraction; F3= oxidisable-organic fraction; F4= resistant fraction; SUM= summation of F1, F2, F3 and F4.

Table S4. Comparisons of concentrations (mg/kg dry weight) of Zn, Cu, Fe, Ni and Pb between surface sediments from this study with those cited from sediment quality guidelines, and reference values.

	Zn	Cu	Fe	Ni	Pb	References
Reference values			-			
Pre-industrial reference level	175	50.0	-	NA	70.0	Hakanson [1]
Upper continental crust	52.0	14.3	43000	19.0	17.0	Wedepohl [2]
Upper continental crust	71.0	25.0	-	44.0	17.0	Taylor and McLennan [3]
Upper continental crust	67.0	28.0	-	47.0	17.0	Rudnick and Gao [4]
Background of WCPM	-	3.55	-	-	-	Yap <i>et al.</i> [5]
Background of WCPM	-	-	-	7.31	-	Yap <i>et al.</i> [6]
Background of WCPM	-	-	-	-	19.48	Yap and Noorhaidah [7]
Background of WCPM	13.16	-	-	-	-	Yap <i>et al.</i> [8]
Mangrove of west coast of PM	29.4-130	5.59-28.7	-	-	25.4-173	Cheng and Yap [9]
Mangrove of west coast of PM	-	-	-	4.33-24.1	-	Cheng <i>et al.</i> [10]
Sediment Quality Guidelines						
Effect range low (ERL)	150	34.0	-	20.9	46.7	Long <i>et al.</i> [11]
Effects range median (ERM)	410	270	-	51.6	218	Long <i>et al.</i> [11]
Threshold effect level (TEL)	124	18.7	-	15.9	30.2	Macdonald <i>et al.</i> [12]
Probable effect level (PEL)	271	108	-	42.8	112	Macdonald <i>et al.</i> [12]
Interim sediment quality value (ISQV)-low	200	65.0	-	40.0	75.0	Chapman <i>et al.</i> [13]
Interim sediment quality value (ISQV)-high	410	270	-	NA	218	Chapman <i>et al.</i> [13]

Table S5. Mean concentrations (mg/kg dry weight) of Fe in the leaf parts (lamina (L); midrib plus petiole (MP)) of *Rhizophora apiculata* and their habitat geochemical fraction sediments, with their bioconcentration factor (BCF) values in the mangrove of Sepang Besar River (1-4), and Lukut River (5-9) from the present study.

Site	Part	Plant	F1	F2	F3	F4	SUM	Total	BCF1	BCF2	BCF3	BCF4	BCF5
1	L	233	119	1016	2197	24475	27808	25512	1.95	0.23	0.106	0.010	0.008
2	L	88.4	249	835	3325	12560	16968	17012	0.36	0.11	0.027	0.007	0.005
3	L	63.2	816	1451	6380	20424	29071	32489	0.08	0.04	0.010	0.003	0.002
4	L	76.4	199	1102	2599	18241	22140	13564	0.38	0.07	0.029	0.004	0.003
5	L	303	751	1618	10364	17152	29885	25728	0.40	0.19	0.029	0.018	0.010
6	L	337	267	1536	7366	28547	37716	31204	1.26	0.22	0.046	0.012	0.009
7	L	260	100	1013	5352	29341	35805	24556	2.61	0.26	0.049	0.009	0.007
8	L	349	113	1149	3414	24613	29289	21200	3.09	0.30	0.102	0.014	0.012
9	L	424	410	1755	7946	22054	32166	26493	1.03	0.24	0.053	0.019	0.013
1	MP	203	119	1016	2197	24475	27808	25512	1.70	0.20	0.093	0.008	0.007
2	MP	51.2	249	835	3325	12560	16968	17012	0.21	0.06	0.015	0.004	0.003
3	MP	28.6	816	1451	6380	20424	29071	32489	0.03	0.02	0.004	0.001	0.001
4	MP	27.1	199	1102	2599	18241	22140	13564	0.14	0.02	0.010	0.001	0.001
5	MP	217	751	1618	10364	17152	29885	25728	0.29	0.13	0.021	0.013	0.007
6	MP	138	267	1536	7366	28547	37716	31204	0.52	0.09	0.019	0.005	0.004
7	MP	138	100	1013	5352	29341	35805	24556	1.38	0.14	0.026	0.005	0.004
8	MP	180	113	1149	3414	24613	29289	21200	1.59	0.16	0.053	0.007	0.006
9	MP	213.0	410	1755	7946	22054	32166	26493	0.52	0.12	0.027	0.010	0.007

Note: BCF1= leave/F1; BCF2= leave/F2; BCF3= leave/F3; BCF4= leave/F4; BCF5= leave/SUM; F1= easily, freely or exchangeable fraction; F2= acid-reducible fraction; F3= oxidisable-organic fraction; F4= resistant fraction; SUM= summation of F1, F2, F3 and F4.

Table S6. Mean concentrations (mg/kg dry weight) of Pb in the leaf parts (lamina (L); midrib plus petiole (MP)) of *Rhizophora apiculata* and their habitat geochemical fraction sediments, with their bioconcentration factor (BCF) values in the mangrove of Sepang Besar River (1-4), and Lukut River (5-9) from the present study.

Site	Part	Plant	F1	F2	F3	F4	SUM	Total	BCF1	BCF2	BCF3	BCF4	BCF5
1	L	0.42	0.71	1.02	6.38	27.5	35.6	25.6	0.59	0.41	0.07	0.02	0.01
2	L	2.73	1.93	1.69	7.38	15.8	26.8	28.3	1.41	1.62	0.37	0.17	0.10
3	L	3.33	1.72	1.39	11.1	23.5	37.7	41.3	1.94	2.40	0.30	0.14	0.09
4	L	0.69	1.20	1.20	5.45	19.0	26.8	29.1	0.58	0.58	0.13	0.04	0.03
5	L	2.33	1.13	1.34	4.93	21.4	28.8	28.9	2.06	1.74	0.47	0.11	0.08
6	L	4.61	1.80	0.43	7.74	32.8	42.8	38.9	2.56	10.7	0.60	0.14	0.11
7	L	8.43	1.29	0.63	7.58	33.0	42.5	41.7	6.53	13.4	1.11	0.26	0.20
8	L	4.33	1.05	0.10	7.59	28.7	37.4	44.8	4.12	43.3	0.57	0.15	0.12
9	L	6.39	1.03	0.32	9.28	31.7	42.4	47.4	6.20	20.0	0.69	0.20	0.15
1	MP	5.25	0.71	1.02	6.38	27.5	35.6	25.6	7.39	5.15	0.82	0.19	0.15
2	MP	9.88	1.93	1.69	7.38	15.8	26.8	28.3	5.12	5.85	1.34	0.63	0.37
3	MP	7.06	1.72	1.39	11.1	23.5	37.7	41.3	4.10	5.08	0.63	0.30	0.19
4	MP	7.63	1.20	1.20	5.45	19.0	26.8	29.1	6.36	6.36	1.40	0.40	0.28
5	MP	6.86	1.13	1.34	4.93	21.4	28.8	28.9	6.07	5.12	1.39	0.32	0.24
6	MP	8.68	1.80	0.43	7.74	32.8	42.8	38.9	4.82	20.2	1.12	0.26	0.20
7	MP	6.40	1.29	0.63	7.58	33.0	42.5	41.7	4.96	10.2	0.84	0.19	0.15
8	MP	8.41	1.05	0.10	7.59	28.7	37.4	44.8	8.01	84.1	1.11	0.29	0.22
9	MP	6.31	1.03	0.32	9.28	31.7	42.4	47.4	6.13	19.7	0.68	0.20	0.15

Note: BCF1= leave/F1; BCF2= leave/F2; BCF3= leave/F3; BCF4= leave/F4; BCF5= leave/SUM; F1= easily, freely or exchangeable fraction; F2= acid-reducible fraction; F3= oxidisable-organic fraction; F4= resistant fraction; SUM= summation of F1, F2, F3 and F4.

Table S7. Mean concentrations (mg/kg dry weight) of Cu in the leaf parts (lamina (L); midrib plus petiole (MP)) of *Rhizophora apiculata* and their habitat geochemical fraction sediments, with their bioconcentration factor (BCF) values in the mangrove of Sepang Besar River (1-4), and Lukut River (5-9) from the present study.

Site	Part	Plant	F1	F2	F3	F4	SUM	Total	BCF1	BCF2	BCF3	BCF4	BCF5
1	L	13.4	0.19	0.38	7.54	19.4	27.5	22.7	70.6	35.3	1.78	0.69	0.49
2	L	6.49	0.03	0.24	3.60	8.40	12.3	11.5	216	27.0	1.80	0.77	0.53
3	L	1.85	0.05	0.13	4.47	11.5	16.1	15.3	37.0	14.2	0.41	0.16	0.11
4	L	2.26	0.01	0.14	2.62	5.92	8.69	9.00	226	16.1	0.86	0.38	0.26
5	L	5.77	0.13	0.03	4.29	8.83	13.3	13.8	44.4	192	1.34	0.65	0.43
6	L	2.12	0.39	0.05	17.3	22.0	39.6	20.1	5.44	42.4	0.12	0.10	0.05
7	L	4.06	0.19	0.14	9.24	16.4	25.9	11.3	21.4	29.0	0.44	0.25	0.16
8	L	3.48	0.14	0.11	6.37	13.5	20.1	9.37	24.9	31.6	0.55	0.26	0.17
9	L	0.69	0.12	0.07	8.73	15.9	24.8	9.52	5.75	9.86	0.08	0.04	0.03
1	MP	10.8	0.19	0.38	7.54	19.4	27.5	22.7	56.7	28.4	1.43	0.55	0.39
2	MP	3.65	0.03	0.24	3.60	8.40	12.3	11.5	122	15.2	1.01	0.43	0.30
3	MP	1.53	0.05	0.13	4.47	11.5	16.1	15.3	30.6	11.8	0.34	0.13	0.09
4	MP	1.54	0.01	0.14	2.62	5.92	8.69	9.00	154	11.0	0.59	0.26	0.18
5	MP	5.24	0.13	0.03	4.29	8.83	13.3	13.8	40.3	175	1.22	0.59	0.39
6	MP	1.96	0.39	0.05	17.3	22.0	39.6	20.1	5.03	39.2	0.11	0.09	0.05
7	MP	3.05	0.19	0.14	9.24	16.4	25.9	11.3	16.1	21.8	0.33	0.19	0.12
8	MP	2.65	0.14	0.11	6.37	13.5	20.1	9.37	18.9	24.1	0.42	0.20	0.13
	MP	1.96	0.12	0.07	8.73	15.9	24.8	9.52	16.3	28.0	0.22	0.12	0.08

Note: BCF1= leave/F1; BCF2= leave/F2; BCF3= leave/F3; BCF4= leave/F4; BCF5= leave/SUM; F1= easily, freely or exchangeable fraction; F2= acid-reducible fraction; F3= oxidisable-organic fraction; F4= resistant fraction; SUM= summation of F1, F2, F3 and F4.

Table S8. Mean concentrations (mg/kg dry weight) of Ni in the leaf parts (lamina (L); midrib plus petiole (MP)) of *Rhizophora apiculata* and their habitat geochemical fraction sediments, with their bioconcentration factor (BCF) values in the mangrove of Sepang Besar River (1-4), and Lukut River (5-9) from the present study.

Site	Part	Plant	F1	F2	F3	F4	SUM	Total Ni	BCF1	BCF2	BCF3	BCF4	BCF5
1	L	2.79	0.27	0.25	5.51	9.68	15.71	13.12	10.33	11.16	0.51	0.29	0.18
2	L	1.35	0.39	0.14	3.57	5.72	9.82	9.90	3.46	9.64	0.38	0.24	0.14
3	L	1.56	0.53	0.28	6.06	8.54	15.39	16.10	2.94	5.57	0.26	0.18	0.10
4	L	2.36	0.35	0.25	2.61	4.84	8.06	8.49	6.74	9.44	0.90	0.49	0.29
5	L	1.48	0.22	0.59	2.74	6.01	9.57	10.11	6.73	2.51	0.54	0.25	0.15
6	L	3.60	0.30	0.42	4.41	8.30	13.42	13.29	12.00	8.57	0.82	0.43	0.27
7	L	2.63	0.03	0.54	3.95	9.50	14.01	11.53	87.67	4.87	0.67	0.28	0.19
8	L	3.32	0.65	0.50	3.03	8.00	12.18	11.23	5.11	6.64	1.10	0.42	0.27
9	L	2.15	0.78	0.19	4.19	8.67	13.84	17.10	2.76	11.32	0.51	0.25	0.16
1	MP	6.05	0.27	0.25	5.51	9.68	15.71	13.12	22.41	24.20	1.10	0.63	0.39
2	MP	1.79	0.39	0.14	3.57	5.72	9.82	9.90	4.59	12.79	0.50	0.31	0.18
3	MP	2.62	0.53	0.28	6.06	8.54	15.39	16.10	4.94	9.36	0.43	0.31	0.17
4	MP	1.94	0.35	0.25	2.61	4.84	8.06	8.49	5.54	7.76	0.74	0.40	0.24
5	MP	2.70	0.22	0.59	2.74	6.01	9.57	10.11	12.27	4.58	0.99	0.45	0.28
6	MP	2.71	0.30	0.42	4.41	8.30	13.42	13.29	9.03	6.45	0.61	0.33	0.20
7	MP	3.66	0.03	0.54	3.95	9.50	14.01	11.53	122.00	6.78	0.93	0.39	0.26
8	MP	4.11	0.65	0.50	3.03	8.00	12.18	11.23	6.32	8.22	1.36	0.51	0.34
9	MP	2.70	0.78	0.19	4.19	8.67	13.84	17.10	3.46	14.21	0.64	0.31	0.20

Note: BCF1= leave/F1; BCF2= leave/F2; BCF3= leave/F3; BCF4= leave/F4; BCF5= leave/SUM; F1= easily, freely or exchangeable fraction; F2= acid-reducible

fraction; F3= oxidisable-organic fraction; F4= resistant fraction; SUM= summation of F1, F2, F3 and F4.

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