Supplementary Information

Source and Ecological Risk Assessment of Potentially Toxic Metals in Urban Riverine Sediments Using Multivariate Analytical and Statistical Tools

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Table S1. Coordinates of sampling locations.

N	Area	Location		Remarks
S-1	Lubanwala Skp	31.71675 N	74.46149 E	Agricultural Area
S-2	Talwara Par	31.69571 N	74.41348 E	Agricultural Area
S-3	Bukanwal	31.65861 N	74.38329 E	Village Area
S-4	Dandian Skp	31.67617 N	74.34534 E	Village Area
S-5	Sialkot-Lhr Motorway	31.67326 N	74.34346 E	Traffic Area
S-6	Badami Bagh	31.6189 N	74.32013 E	Industrial Area
S-7	Old Ravi Bridge	31.61099 N	74.30102 E	Industrial + Traffic
S-8	Batti Chowk	31.60566 N	74.29503 E	Traffic Area
S-9	Kareem Park	31.59235 N	74.28048 E	Industrial Area
S-10	Saggian Bridge	31.57684 N	74.26439 E	Industrial + Traffic Area
S-11	Saggian Bypass	31.5688 N	74.26255 E	Plastic Factory Area
S-12	M-2 Toll Plaza	31.55285 N	74.24262 E	Traffic Area
S-13	Hanjarwal	31.52554 N	74.20974 E	Forest Reserve
S-14	Shahpur	31.49673 N	74.18767 E	Agricultural Area
S-15	Pak View City	31.47042 N	74.17895 E	Residential Society
S-16	Dhana	31.44774 N	74.14997 E	Agricultural Area
S-17	Jhok, Maraka	31.4326 N	74.13394 E	Forest Reserve
S-18	Mohlanwal	31.41219 N	74.12102 E	Boating Point
S-19	Khudpur	31.40711 N	74.10122 E	Municipal Drain Connection
S-20	Shariqpur	31.40882 N	74.06427 E	Chenab Canal Connection
S-21	Nawakot	31.35728 N	74.25729 E	Agricultural Area
S-22	Manga	31.32287 N	74.00831 E	Agricultural Area
S-23	Faizpur Kala	31.32317 N	73.97043 E	Agri + Residential Area
S-24	Karianwala Qasur	31.30653 N	73.9275 E	Agri + Residential Area
S-25	Morkhunda	31.25417 N	73.88904 E	Agricultural Area

Table S2. Comparison of the applicability and interpretation of pollution assessment indices used in the study.

Indices	Applicability	Interpretation
Geo-accumulation Index (Igeo)	Provides identification of significant anthropogenic pollution but may underestimate pollution in areas with naturally high background levels.	Used to assess the degree of heavy metal contamination in sediments, particularly for elements with relatively low background concentrations.
Enrichment Factor (EF)	Used to differentiate between natural and anthropogenic sources of pollution, particularly for elements with variable background concentrations.	The EF quantifies the degree of anthropogenic influence on metal concentrations in sediments relative to background levels. Higher EF values indicate greater anthropogenic input.
Contamination Factor (CF)	Useful for a quick pollution assessment but may not be as accurate as other methods.	Used to assess the degree of contamination and identify areas of concern.
Pollution Load Index (PLI)	It provides a holistic view of pollution but may be influenced by the selection of metals. It is used to assess the overall pollution level in river sediments.	The PLI combines the contamination factors of multiple metals to provide a comprehensive assessment of overall pollution.
Ecological Risk Index (ERI)	Provides a more comprehensive assessment of ecological risk but may be limited by the availability of toxicity data.	Used to assess the potential ecological risks associated with PTMs contamination.
Modified Hazard Quotient (mHQ)	Helpful in assessing human health risks but may not be suitable for all exposure scenarios.	Used to assess the potential human health risks associated with exposure to PTMs in sediments.
Integrated Toxic Risk Index (ITRI)	It provides a more comprehensive assessment of human health and ecological risks, but it is complex to calculate and requires extensive data.	Used to assess the overall risk associated with PTMs contamination, considering both toxicity and bioavailability.
Nemerow Pollution Index (NPI)	Useful for a quick assessment of pollution.	Used to provide a general assessment of pollution levels.
Sediment Quality Guidelines (SQGs)	Provides a direct comparison of measured concentrations to established guidelines.	Used to assess the ecological health of sediments by comparing measured concentrations to established guidelines.

Table S3. Pollution levels interpretation of PTMs contamination in sediment samples employed various assessment methods [1–3].

Methods	Class	Values range	Pollution level interpretation
Igeo			
	0	$I_{geo} < 0$	No accumulation
	1	$0 \leq I_{geo} < 1$	No to moderate accumulation
	2	$1 \leq I_{geo} < 2$	Moderate accumulation
	3	$2 \leq I_{geo} < 3$	Moderate to heavy accumulation
	4	$3 \leq I_{geo} < 4$	Heavy accumulation
	5	$4 \leq I_{geo} < 5$	Heavy to extreme accumulation
	6	$I_{geo} \geq 5$	Extreme accumulation
EF			
	0	EF < 2	Minimum Enrichment
	1	$2 \leq$ EF < 5	Moderate Enrichment
	2	$5 \leq$ EF < 20	Significant Enrichment
	3	$20 \leq$ EF < 40	High Enrichment
	4	EF $\geq$ 40	Extreme Enrichment
CF			
	1	CF < 1	Low Contamination
	2	$1 \leq$ CF < 3	Moderate Contamination
	3	$3 \leq$ CF < 6	High Contamination
	4	CF $\geq$ 6	Extreme Contamination
PLI			
	1	PLI < 1	No Significant Pollution
	2	PLI = 1	Baseline Level Pollution
	3	PLI > 1	Significant Pollution
Er$_i$			
	1	Er$_i$ < 40	Low Ecological Risk
	2	$40 \leq$ Er$_i$ < 80	Moderate Ecological Risk
	3	$80 \leq$ Er$_i$ < 160	Considerable Ecological Risk
	4	$160 \leq$ Er$_i$ < 320	High Ecological Risk
	5	Er$_i$ $\geq$ 320	Extreme Ecological Risk
PERI			
	1	MRI < 150	Low Risk
	2	$150 \leq$ MRI < 300	Moderate Risk
	3	$300 \leq$ MRI < 600	Considerable Risk
	4	MRI $\geq$ 600	High Risk
mHQ			
	1	0 < mHQ < 0.5	Absent
	2	0.5 < mHQ < 1	Very Low

3	$1 < mHQ < 1.5$	Low
4	$1.5 < mHQ < 2$	Moderate
5	$2 < mHQ < 2.5$	Significant
6	$2.5 < mHQ < 3$	High
7	$3 < mHQ < 3.5$	Very High
8	$3.5 < mHQ$	Extreme

ITRI

1	$TRI < 5$	No Toxicity Risk
2	$5 \leq TRI < 10$	Low Toxicity Risk
3	$10 \leq TRI < 15$	Moderate Toxicity Risk
4	$15 \leq TRI < 20$	Considerable Toxicity Risk
5	$TRI \geq 20$	Extreme Toxicity Risk

Table S4. Summary of sediment quality guidelines ERL, ERM, TEL, PEL, and SEL concentration of PTMs (mgkg^{-1}) [4,5].

SQGs (ppm)	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
ERL	8.2	1.2	81	34	0.15	20.9	46.7	150
ERM	70	9.6	370	270	0.71	51.6	218	410
TEL	7.24	0.68	52.3	18.7	0.13	15.9	30.2	124
PEL	41.6	4.21	160	108	0.7	42.8	112	271
SEL	33	10	110	110	2	250	75	820

Table S5. Eigenvector coefficients of the PTMs with respective PCs.

PTMs	Factor loadings		
	PC1	PC2	PC3
Al	0.27	0.13	-0.19
As	0.25	-0.13	0.0
Cd	0.21	0.23	-0.18
Co	0.31	0.21	-0.01
Cr	-0.10	0.39	0.52
Cu	0.20	-0.35	0.23
Fe	0.32	0.06	0.07
Hg	0.21	0.17	-0.02
Mn	0.22	0.43	-0.17
Ni	0.32	-0.07	0.19
Pb	0.29	-0.14	-0.06
Sb	-0.01	0.40	0.59
Sn	0.30	-0.16	0.17
Sr	0.11	0.34	-0.38
V	0.31	-0.04	0.07
Zn	0.29	-0.22	0.16
Eigenvalues	7.90	2.33	1.84
% Variance	49.4%	14.6%	11.6%
Cumulative	49.4%	64.0%	75.6%
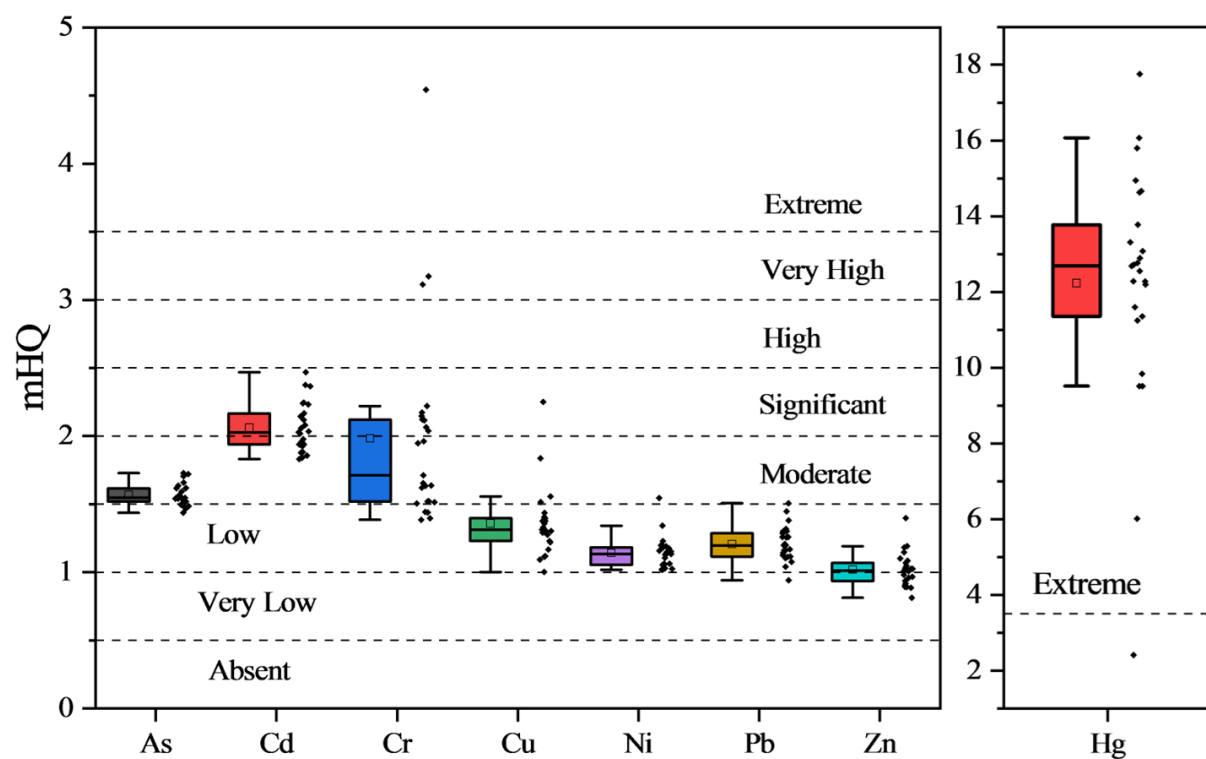
Fig. S1. The box plots show the mean, median, and range of values for modified hazard quotient of PTMs studied in the sediment sample of River Ravi.
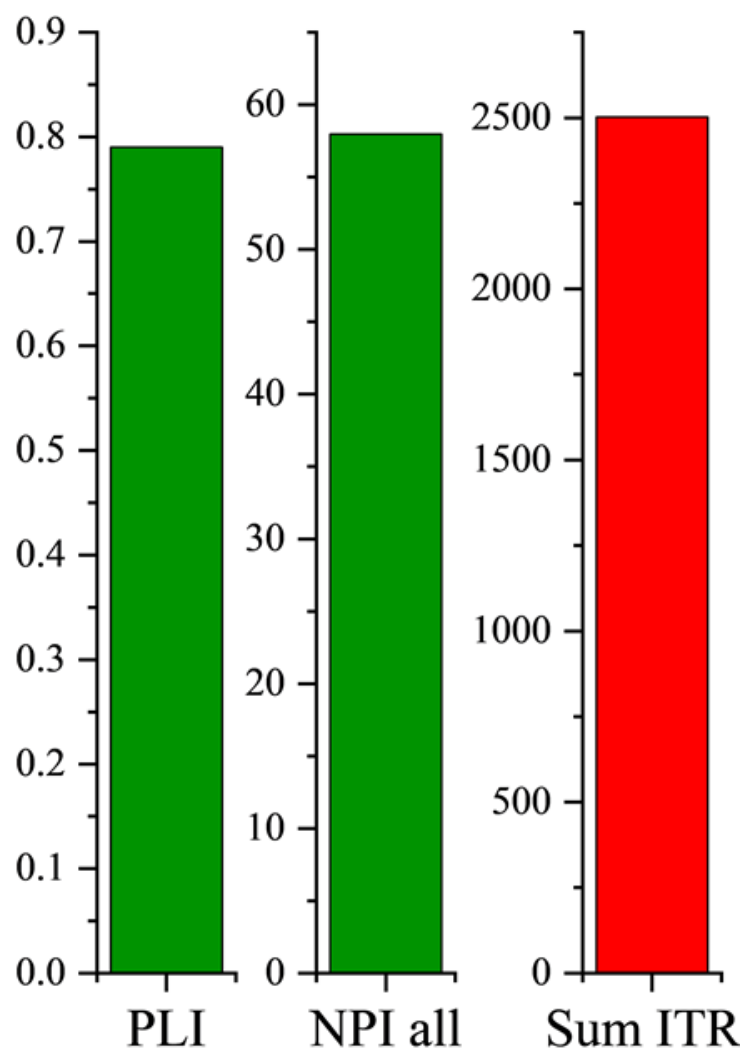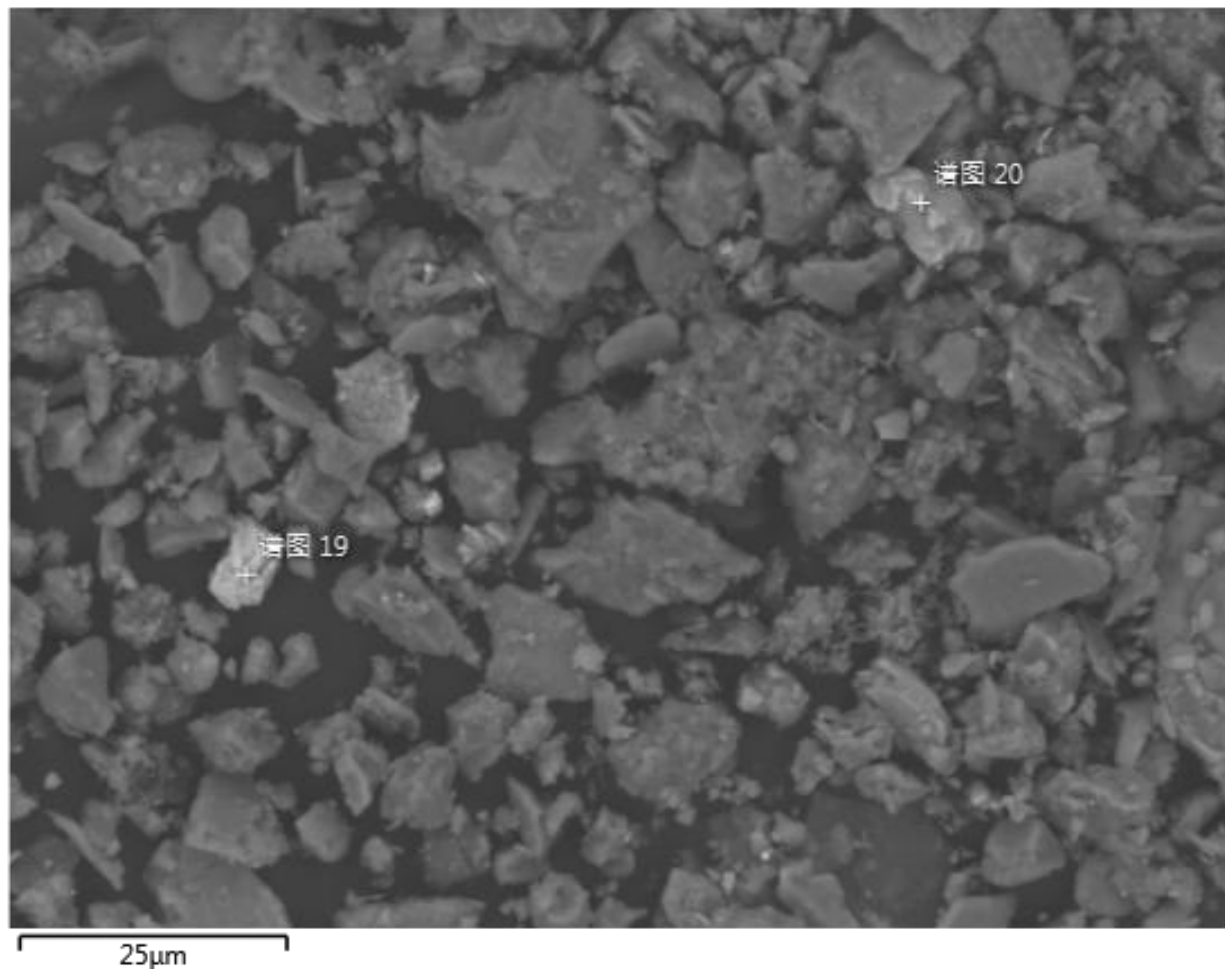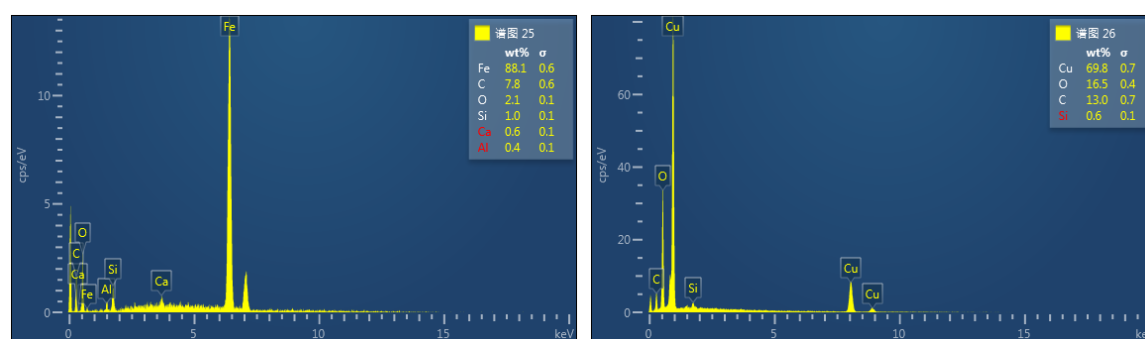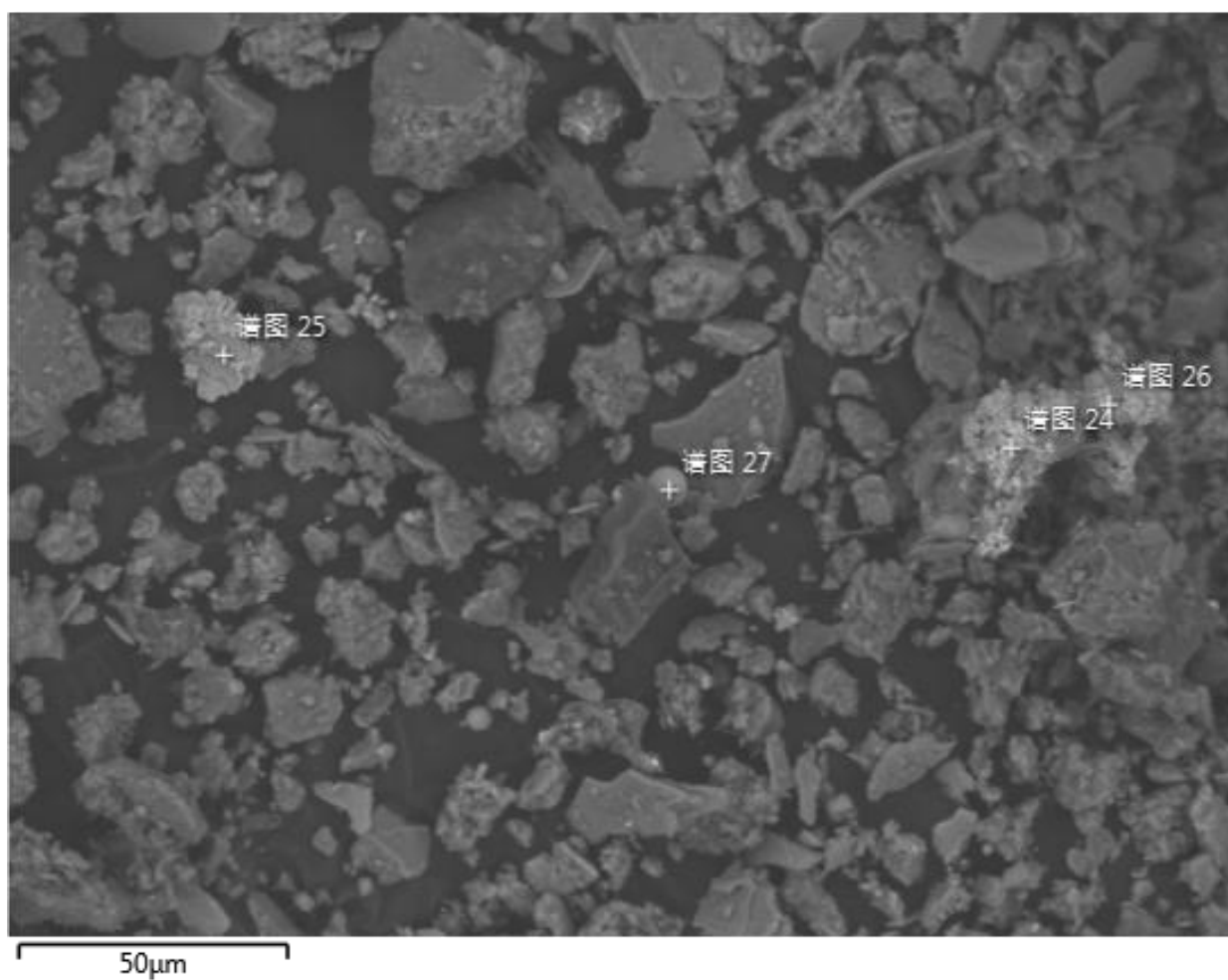
Fig. S2. Bar chart illustrations based on pollution load index (PLI), Nemerow pollution index (NPI) and sum of integrated toxicity risk (ITR) of PTMs in the sediments of River Ravi.
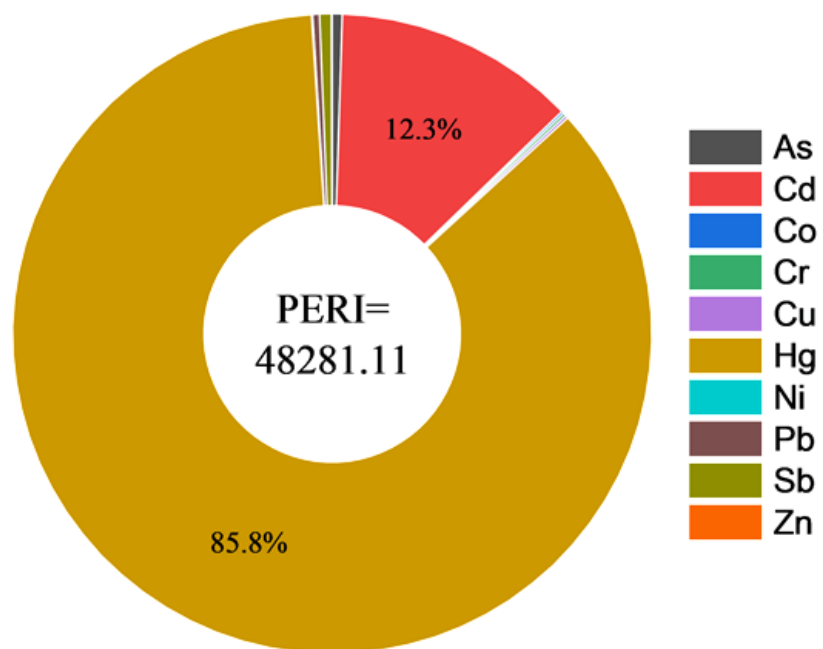
Fig. S3. This pie chart illustrates the potential ecological risk index (PERI) of PTMs in the sediments of the River Ravi.
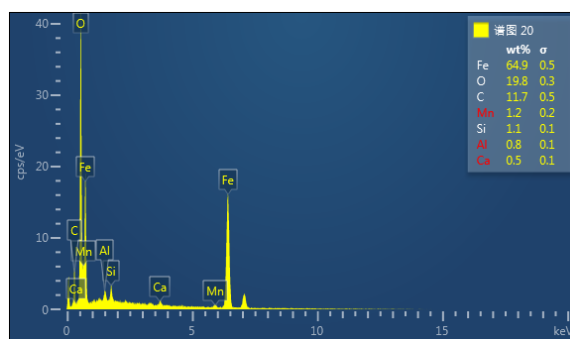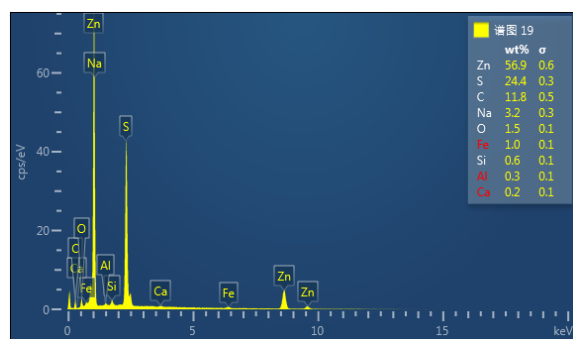
Fig. S4 (a). SEM and EDS from sediment sample showing Zn and Fe.

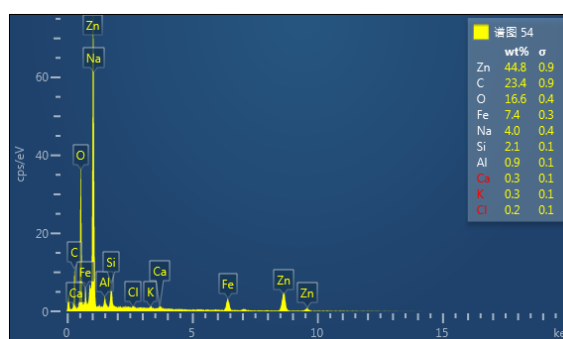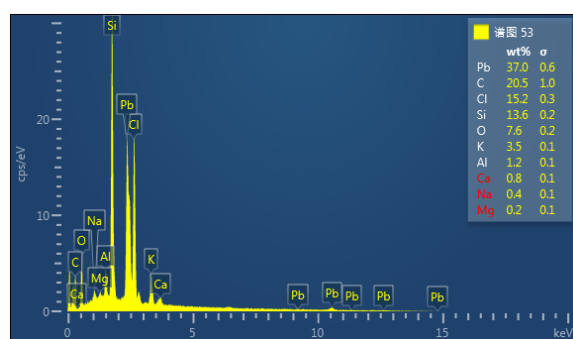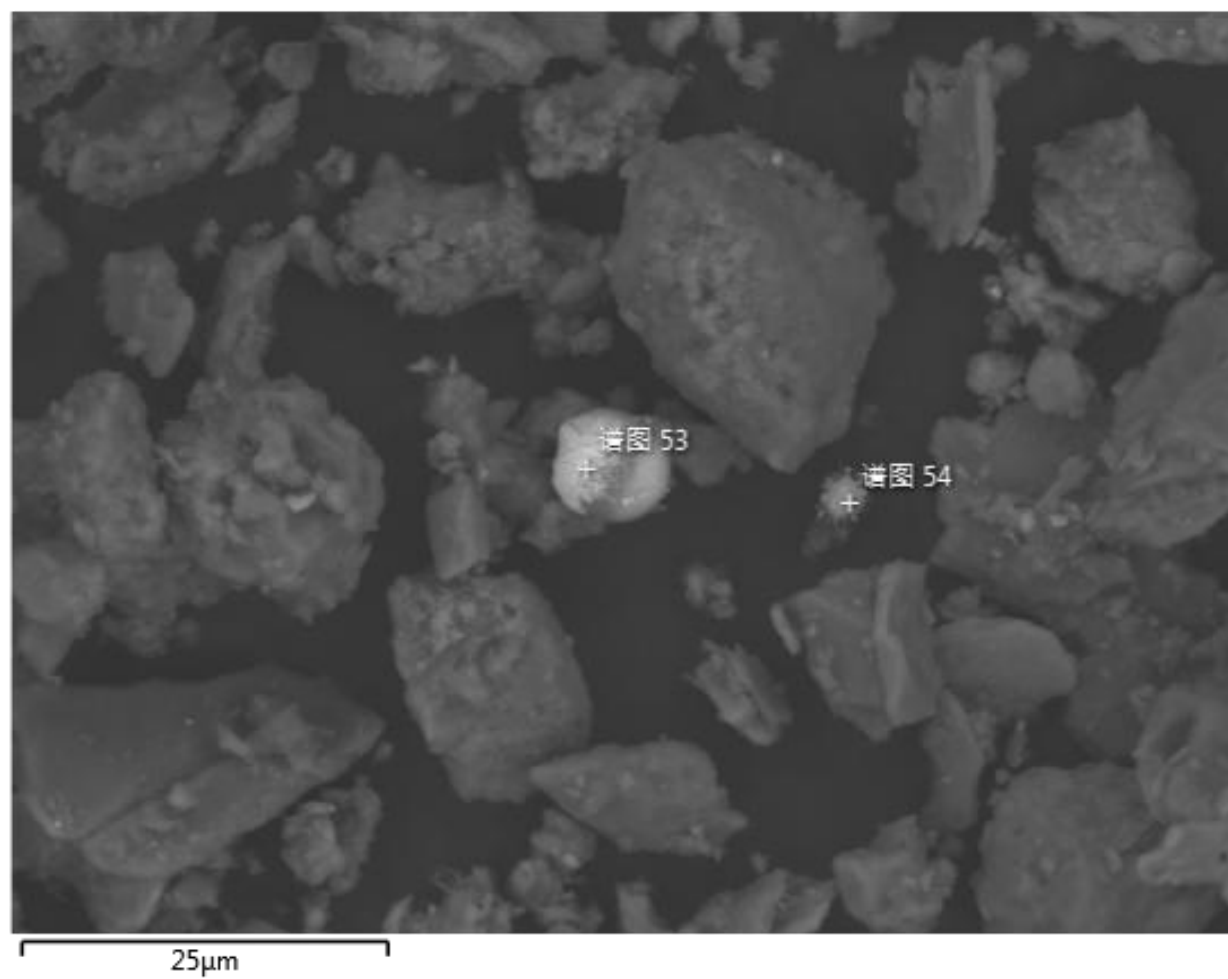**Fig. S4 (b).** SEM and EDS from sediment sample showing Cu and Fe.

Fig. S4 (c). SEM and EDS from sediment sample showing Pb and Zn.

References

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