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Ecological Risk Due to Heavy Metal Contamination in Sediment and Water of Natural Wetlands with Tourist Influence in the Central Region of Peru

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Supplementary Materials

Table S1. Description of individual indices, methods and categorizations used in sediment assessment.

Index	Aplication	Method	Categorization	References
Contamination factor (Cf)	The relationship between the concentration of each metal in the sediment and the background value is applied to quantify the metal contamination status of the sediment, helping to describe the individual toxic substances.	$C = \frac{C_m \text{ sample}}{C_m \text{ background}}$ $C_m$sample : Concentration of metal in sediment $C_m$background: Concentration of metal in Upper Continental Crust	< 1; Low CF 1–3; Moderate CF 3–6; Considerable CF ≥ 6; Very high CF	[1,2]
Enrichment factor* (EF)	A tool to estimating the anthropogenic impact of the metals in sediments. This method usually uses the Iron or Aluminum as a tracer or proxy to distinguish or normalize natural from anthropogenic components in the sample.	$EF = \frac{(C_m \text{ sample} \times C_{Fe}\text{background})}{(C_m \text{ background} \times C_{Fe}\text{sample})}$ $C_m$sample : Concentration of metal in sediment $C_m$background: Concentration of metal in Upper Continental Crust C_{Fe}sample : Concentration of iron in sediment C_{Fe}background : Concentration of iron in Upper Continental Crust	< 1; No enrichment 1–3; Minor enrichment 3–5; Moderate enrichment 5–10; Moderately severe enrichment 10–25; Severe enrichment 25–50; Very severe enrichment >50; Extremely severe enrichment.	[2–4]
Geoaccumulation index (Igeo)	Used to determine the difference in concentrations between samples and the background values that exist naturally in the continental crust. This index assess the pollution levels in sediment to each metal evaluated.	$I_{geo} = \log_2 \frac{C_n}{1.5 \times B_n}$ C_n = Concentration of metal in sediment B_n = Concentration of metal in Upper Continental Crust 1.5 = Factor to minimize the effect of possible variations in the background values	≤ 0; class 0 = Uncontaminated 0–1; class 1 = Uncontaminated to moderately contaminated 1–2; class 2 = Moderately contaminated 2–3; class 3 = Moderately to strongly contaminated 3–4; class 4 = Strongly contaminated 4–5; class 5 = Strongly to extremely contaminated > 5; class 6 = Extremely contaminated	[5,6]

*The Iron was used as a proxy because we had the data of this element and it was used in other researches with similar geographical conditions as [7–10].

Table S2. Description of complex indices, methods and categorizations used in sediment assessment.

Index	Aplication	Method	Categorization	References
Pollution Load Index (PLI)	Provide some understanding to the public of the degree of contamination in sediments. An way to determinate the deterioration of the environment as a result of the accumulation of toxic metals.	$PLI = (CF_1 \times CF_2 \times CF_3 \times \ldots CF_n)^{1/n}$ CF_n: Contamination factor of each metal n: Number of metals	< 1; Uncontaminated = 1; Slightly contaminated >1; Environment deterioration	[11,12]
Contamination Modified Degree (mCd)	Assessment of overall degree of contamination of the elements studied. Using this generalized formula to calculate the mCd, from the original Cd, allows the incorporation of as many metals as the study may include.	$mCd = \frac{\sum_{i=1}^{i=n} C_f^i}{n}$ C_f: Contamination factor i: ith metal n: Number of metals	< 1.5; Uncontaminated to very low degree of contamination 1.5–2; Low degree of contamination 2–4; Moderate degree of contamination 4–8; High degree of contamination 8–16; Very high degree of contamination 16–32; Extremely high degree of contamination ≥ 32; Ultra high degree of contamination	[3,6]
Potential Ecological Risk (Ri)	Assess the integrated potential ecological risk from all heavy metals measured in sediments, on ecosystem organisms. Since its model includes the ecological risk and the biological toxic factor of each metal.	$E_r^i = T_r^i \times C_f^i$ $Ri = \sum_{i=1}^{n} E_r^i$ E_r: Ecological risk index of each metal T_r: Biological toxic factor of each metal i: ith metal	< 95; Low potential ecological risk 95–190; Moderate ecological risk 190–380; Considerable ecological risk > 380; Very high ecological risk	[1,13]
Site Rank Index (SRI)*	Allows a better understanding of the sediment pollution status with respect to the environment under study, since it compares the pollution level of sampling sites with respect to the concentrations of elements analyzed under same metrics avoiding the comparison in different classifications of each pollution index (CF, Igeo, EF).	$W = \frac{\sum n_i}{\sum i}$ $SRI = \frac{W}{S} \times 100$ S: Number of sampling stations n: Pollution rank of the site in ascending order (to each value used: Igeo, RI, EF, etc.) i: ith metal	SRI < median - SD; Low pollution median - SD < SRI < median; Moderate pollution median < SRI < median + SD; High pollution median + SD < SRI; Severe pollution	[4,14]

*The SRI was also applied to the metal concentration values of water samples [14].

Table S3. Metal concentration in sediments and surface water of samples collected in Tragadero lagoon.

Sample	Metal concentration in sediments (mg kg^{-1})				Metal concentration in water (mg L^{-1})			
	Pb	Zn	Fe	As	Pb	Zn	Fe	As
1	59.52	71.66	20795.30	20.23	0.026	0.064	0.039	0.025
2	55.43	84.64	21137.20	24.79	0.024	0.065	0.038	0.025
3	53.45	82.50	21431.50	27.09	0.021	0.069	0.033	0.020
4	57.87	80.86	20562.10	17.54	0.021	0.080	0.042	0.019
5	55.50	79.02	17618.70	17.83	0.023	0.081	0.043	0.021
6	52.36	65.42	20578.50	25.14	0.025	0.074	0.039	0.023
7	54.47	74.14	21006.30	19.77	0.024	0.074	0.042	0.024
8	53.31	76.44	12406.60	18.62	0.016	0.074	0.034	0.019
9	53.81	82.66	11575.20	24.57	0.019	0.076	0.028	0.018
10	56.21	72.18	20767.10	28.83	0.014	0.076	0.042	0.024
11	53.46	67.92	20493.10	26.89	0.015	0.077	0.034	0.021
12	47.67	66.44	20277.80	16.21	0.013	0.077	0.041	0.024
13	44.64	77.54	16677.60	19.65	0.017	0.078	0.046	0.021
14	41.99	68.38	11232.90	24.68	0.012	0.080	0.038	0.020
15	48.56	63.24	20354.60	22.40	0.012	0.070	0.034	0.019
16	45.48	73.64	11139.10	24.37	0.009	0.073	0.042	0.022
17	48.02	67.14	17629.80	24.19	0.017	0.087	0.034	0.025
18	43.51	69.78	11315.90	22.40	0.019	0.087	0.043	0.020
19	41.52	66.02	10659.20	22.16	0.018	0.087	0.034	0.024
20	46.12	65.28	20058.60	28.38	0.022	0.089	0.038	0.023
21	48.94	68.74	11555.20	25.22	0.021	0.089	0.046	0.020
22	45.62	64.06	21649.40	20.23	0.021	0.091	0.038	0.021
23	43.21	67.88	11298.60	28.27	0.023	0.092	0.042	0.021
24	42.35	62.62	19871.10	22.27	0.025	0.092	0.039	0.025

Table S4. Metal concentration in sediments and surface water of samples collected in Paca lagoon.

Sample	Metal concentration in sediments (mg kg^{-1})				Metal concentration in water (mg L^{-1})			
	Pb	**Zn**	**Fe**	**As**	**Pb**	**Zn**	**Fe**	**As**
1	53.94	105.52	10107.40	10.79	0.011	0.074	0.019	0.004
2	42.19	104.90	9625.80	12.83	0.010	0.074	0.019	0.003
3	42.21	102.90	9725.80	10.59	0.012	0.074	0.023	0.004
4	45.88	102.56	9342.20	14.63	0.016	0.074	0.019	0.003
5	44.23	94.64	8772.30	15.14	0.011	0.074	0.023	0.004
6	50.33	94.34	10501.40	16.86	0.016	0.075	0.023	0.006
7	52.22	93.72	9245.70	15.03	0.009	0.075	0.023	0.003
8	53.96	92.68	9656.20	14.52	0.013	0.075	0.023	0.004
9	46.73	92.68	8253.60	14.74	0.011	0.080	0.023	0.004
10	46.11	92.58	8642.50	15.22	0.012	0.080	0.023	0.006
11	45.92	84.18	10088.90	10.74	0.014	0.080	0.019	0.004
12	45.19	82.24	8834.20	12.49	0.010	0.082	0.018	0.006
13	45.23	79.76	9154.20	12.76	0.011	0.082	0.023	0.004
14	47.01	79.68	9911.80	10.63	0.013	0.082	0.023	0.006
15	35.56	78.58	9844.90	17.53	0.012	0.083	0.023	0.004
16	42.35	78.38	10479.10	14.82	0.010	0.083	0.019	0.003
17	44.21	77.90	7784.20	13.70	0.014	0.083	0.023	0.004
18	44.87	75.82	9322.30	10.35	0.013	0.084	0.024	0.003
19	47.94	75.76	9450.50	13.70	0.007	0.084	0.023	0.004
20	41.78	75.66	10643.90	12.68	0.010	0.084	0.019	0.004
21	46.65	74.38	9931.20	13.76	0.013	0.084	0.018	0.004
22	47.78	68.72	9753.80	14.82	0.014	0.085	0.023	0.002
23	41.89	68.58	8791.40	14.92	0.011	0.085	0.023	0.004
24	44.96	67.62	10875.00	14.82	0.015	0.086	0.023	0.006

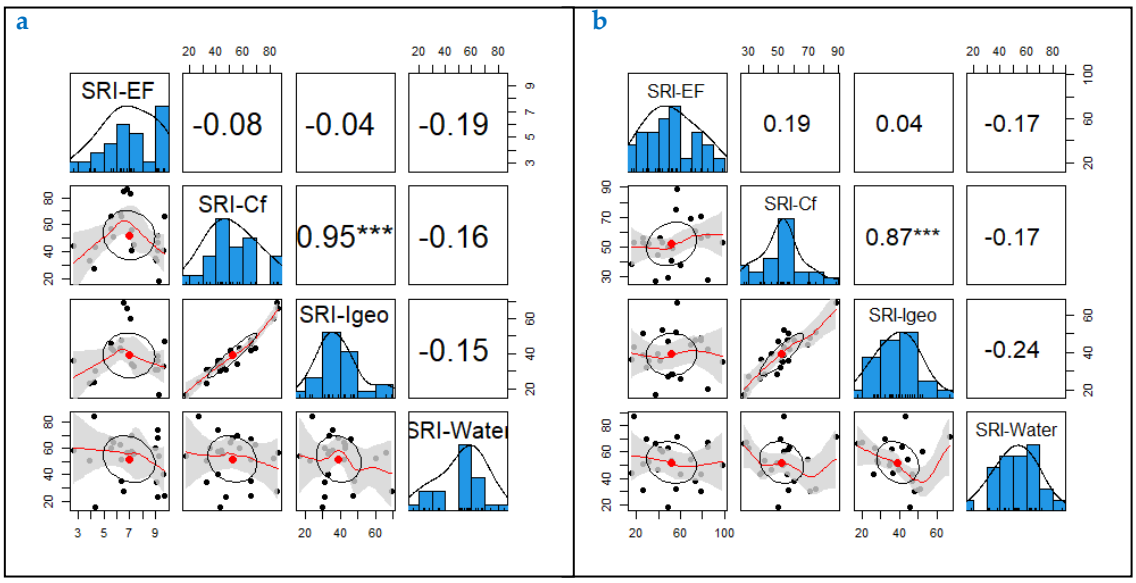

Figure S1. Correlation matrix of SRI calculated from each individual index and metal concentration in water (a: Tragadero lagoon; b: Paca lagoon) (***: High correlation degree).

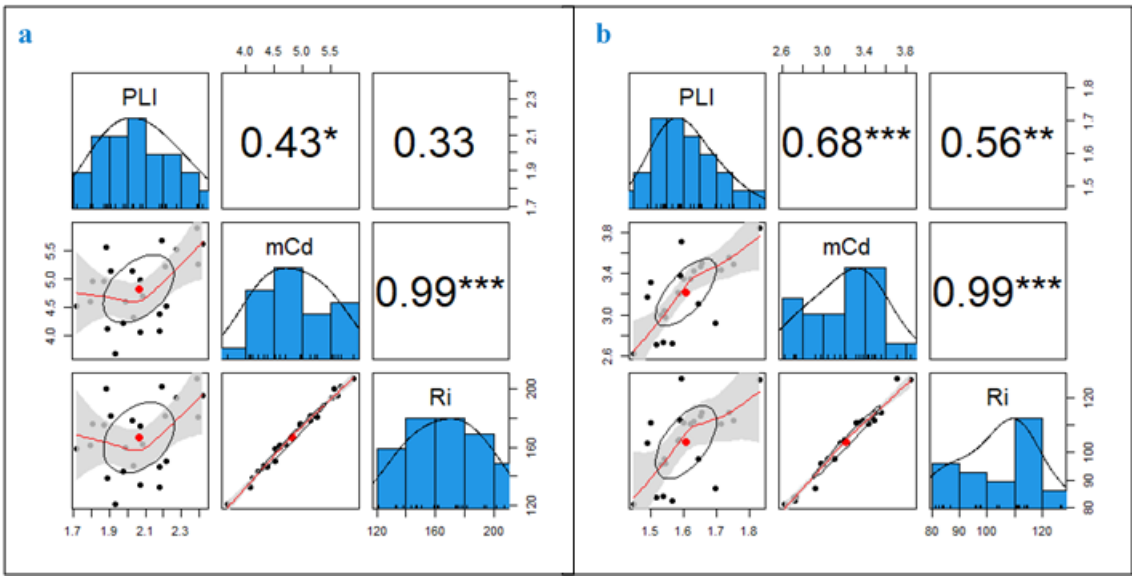

Figure S2. Correlation matrix of PLI, mCd and Ri calculated from sediment samples (a: Tragadero lagoon; b: Paca lagoon) (***: High correlation degree, **: Medium correlation degree, *: Low correlation degree).

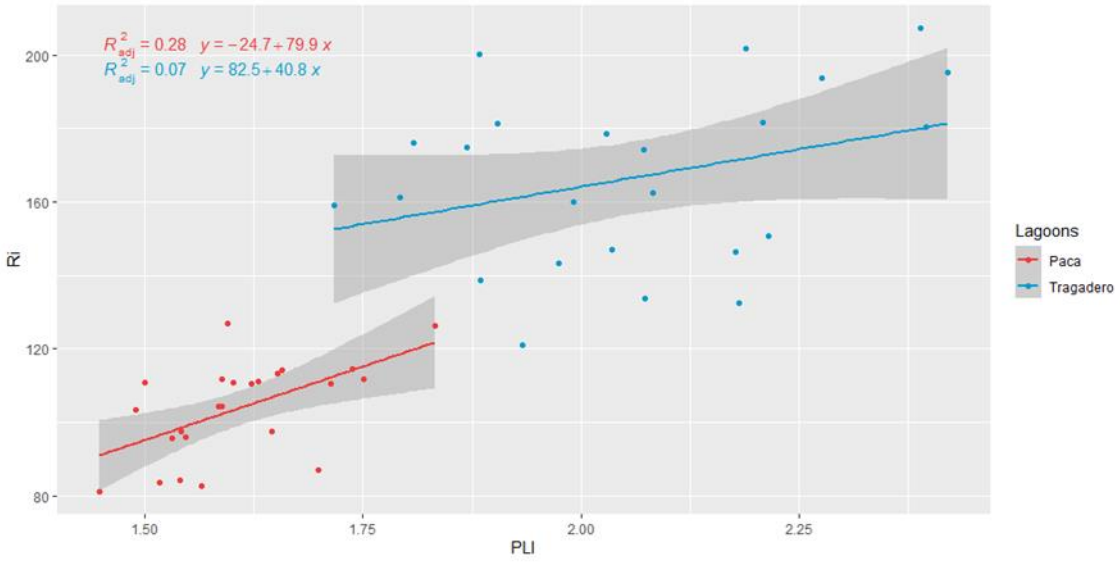

Figure S3. Linear regression between PLI and Ri values of the lagoons.

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