

1. Supplementary materials S1

Risk flow analysis using network environment analysis

Within NEA framework, the risks to soil microorganisms and vegetation can extend to higher-level consumers through their degree of control allocation (CA) (Tang et al., 2017). The CA represents the intensity of the control and can be simulated using the following equations (Lu et al., 2021; Wei et al., 2023).

$$CA = (ca_{ij}) \begin{cases} ca_{ij} = \frac{n_{ij}-n'_{ij}}{\sum_{i=1}^n (n_{ij}-n'_{ij})}, & \text{when } n_{ij} - n'_{ij} > 0 \\ ca_{ij} = 0, & \text{when } n_{ij} - n'_{ij} \leq 0 \end{cases} \quad (1)$$

$$N = (n_{ij}) = G^0 + G^1 + G^2 + \dots + G^m = (1 - G)^{-1} \quad (2)$$

$$N' = (n'_{ij}) = (G')^1 + (G')^2 + (G')^3 + \dots + (G')^m = (1 - G')^{-1} \quad (3)$$

$$G(G') = [g_{ij}][g'_{ij}] \quad (4)$$

$$g_{ij}(g'_{ij}) = \frac{f_{ij}}{T_{ij}} \left(\frac{f'_{ij}}{T'_{ij}} \right) \quad (5)$$

where Ca_{ij} is the control intensity applied from j to i , f_{ij} is the energy or material flow from j to i , T_i (or T_j) is the cumulative inflow or outflow of the i th (or j th) compartment.

Reference for Supplementary materials S1:

Lu, J., Lu, H., Wang, W., Feng, S., Lei, K., 2021. Ecological risk assessment of heavy metal contamination of mining area soil based on land type changes: an information network environ analysis. *Ecological Modelling*, 455: 109633. <https://doi.org/10.1016/j.ecolmodel.2021.109633>.

Tang, P.Z., Liu, J.Z., Lu, H.W., Wang, Z., He, L., 2017. Information-based network environ analysis for ecological risk assessment of heavy metals in soils. *Ecological*

Modelling, 344: 17-28. <https://doi.org/10.1016/j.ecolmodel.2016.10.009>.

Wei, R.F., Meng, Z.R., Zerizghi, T., Luo, J., Guo, Q.J., 2023. A comprehensive method of source apportionment and ecological risk assessment of soil heavy metals: A case study in Qingyuan city, China. *Science of the Total Environment*, 882: 163555. <https://doi.org/10.1016/j.scitotenv.2023.163555>.

2. Supplementary materials (Tables)

Table S1 Newmerow composite pollution index results for heavy metals

	Clean	Precautionary	Slightly polluted	Moderately polluted	Heavily polluted
Sample number	113	40	50	15	11
Region percentage (%)	49.34	17.47	21.83	6.55	4.80

Note: Clean ($NCPI \leq 0.7$); Precautionary ($0.7 < NCPI \leq 1.0$); Slightly polluted ($1.0 < NCPI \leq 2.0$); Moderately polluted ($2.0 < NCPI \leq 3.0$); Heavily polluted ($NCPI > 3.0$).

Table S2: Multiple linear regression equations for studied elements and test results.

Multiple linear regression equation	R ²	P Value
$Cd = 0.021 + 0.044 \times PC1 - 0.009 \times PC2 + 0.238 \times PC3$	0.764	< 0.001
$Pb = 0.643 + 1.976 \times PC1 + 4.693 \times PC2 + 32.03 \times PC3$	0.795	< 0.001
$Cr = 4.79 + 102.755 \times PC1 + 15.88 \times PC2 + 4.287 \times PC3$	0.848	< 0.001
$Ni = -10.978 + 50.411 \times PC1 + 4.902 \times PC2 + 9.906 \times PC3$	0.898	< 0.001

$\text{Cu} = -4.741 + 17.983 \times \text{PC1} + 12.125 \times \text{PC2} + 5.092 \times \text{PC3}$	0.838	< 0.001
$\text{Zn} = -5.549 + 22.604 \times \text{PC1} + 63.207 \times \text{PC2} + 10.223 \times \text{PC3}$	0.821	< 0.001
$\text{Mn} = 101.098 + 343.901 \times \text{PC1} + 222.697 \times \text{PC2} + 27.543 \times \text{PC3}$	0.754	< 0.001
$\text{Fe} = 0.732 + 3.17 \times \text{PC1} + 1.017 \times \text{PC2} + 0.277 \times \text{PC3}$	0.850	< 0.001
$\text{Zn} = 48.191 + 166.229 \times \text{PC1} + 801.559 \times \text{PC2} - 33.679 \times \text{PC3}$	0.858	< 0.001

3. Supplementary materials (Figures)

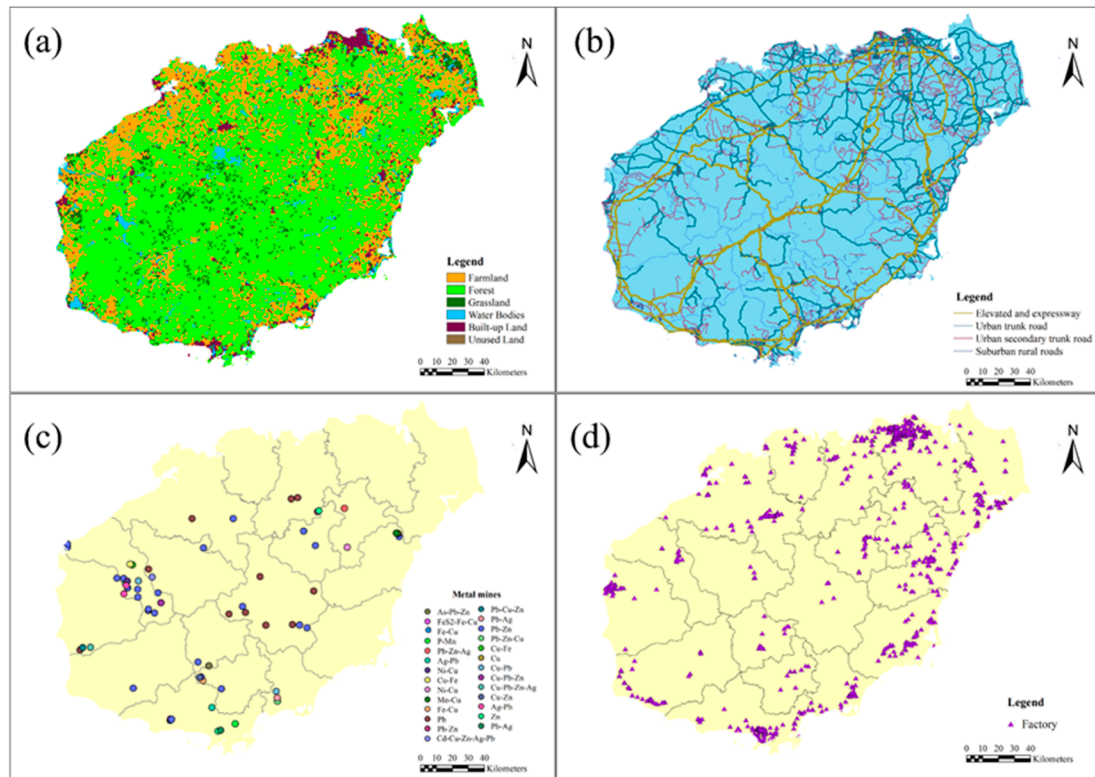


Figure S1. The maps of the factors influencing heavy metal element concentrations in the soils of Hainan Island, including (a) land use; (b) road network; (c) metal mines; and (d) factory sites.

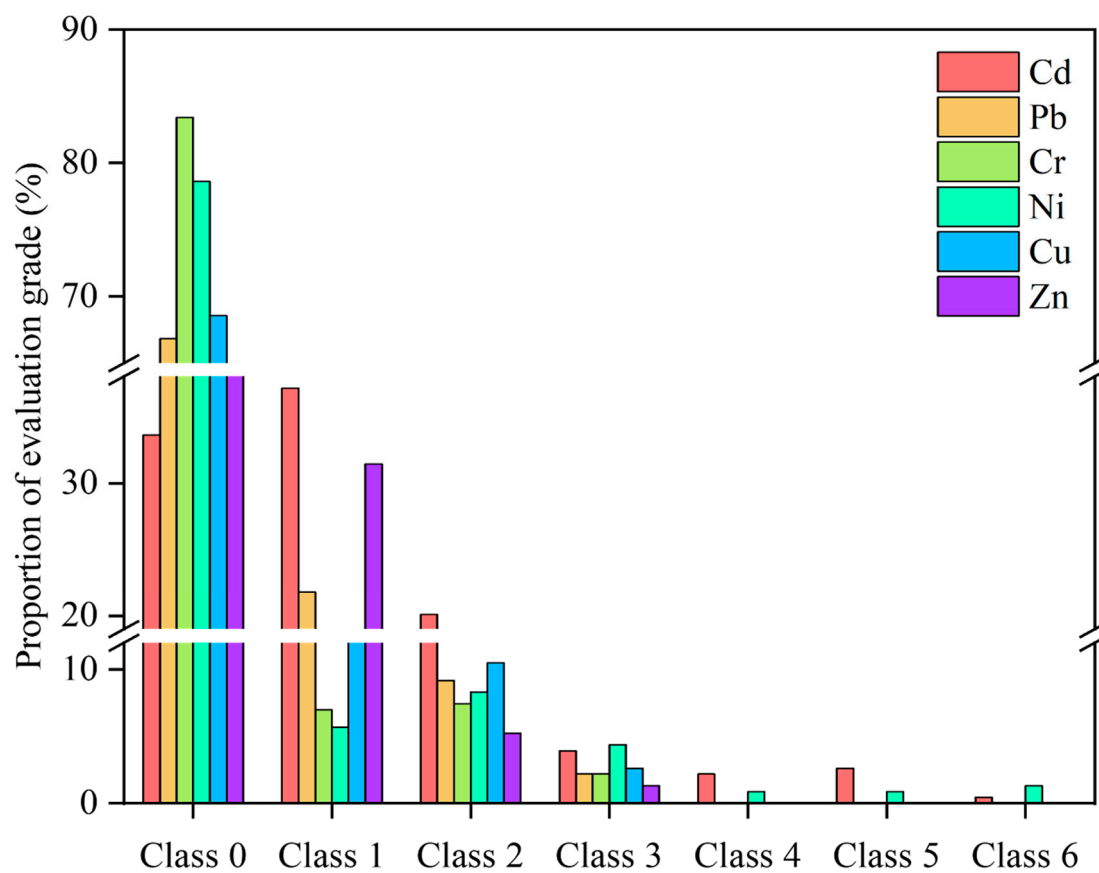


Figure S2. Proportion of different heavy metal content evaluation levels in paddy soils. (Note: Class 0: uncontaminated; Class 1: uncontaminated to moderately contaminated; Class 2: moderately contaminated; Class 3: moderately to heavily contaminated; Class 4: heavily contaminated; Class 5: heavily to extremely contaminated; Class 6: extremely contaminated.)

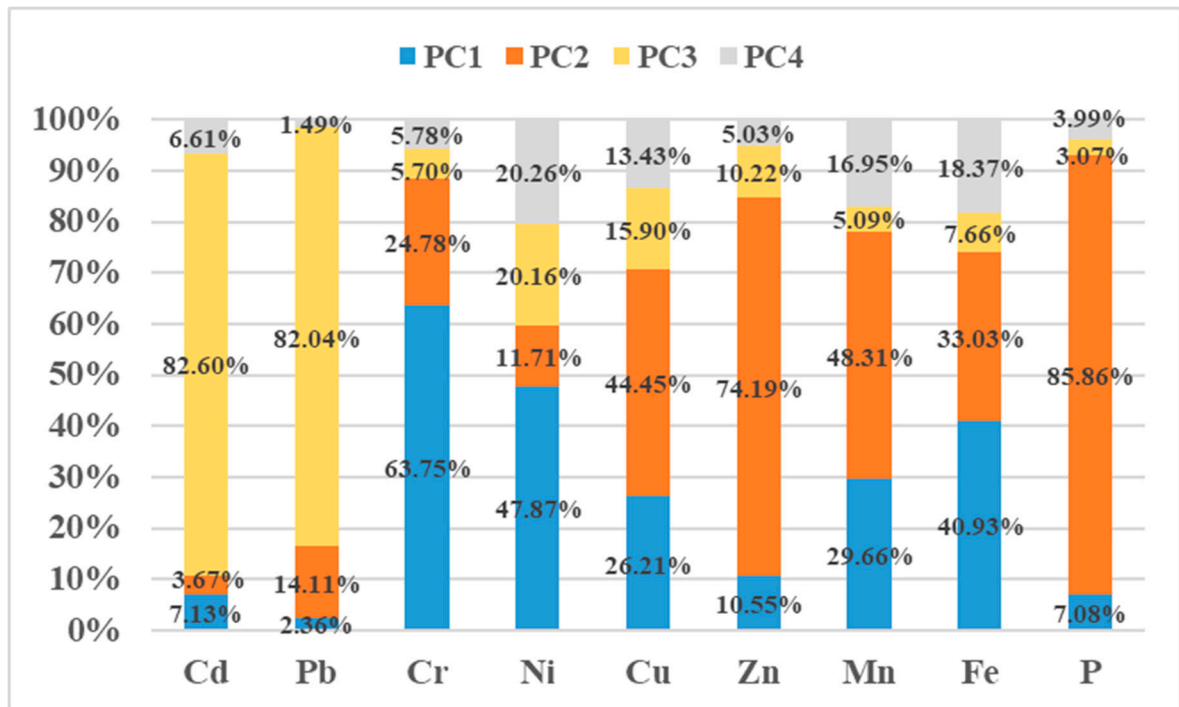


Figure S3. Contribution rate of different pollution sources to each heavy metal element.

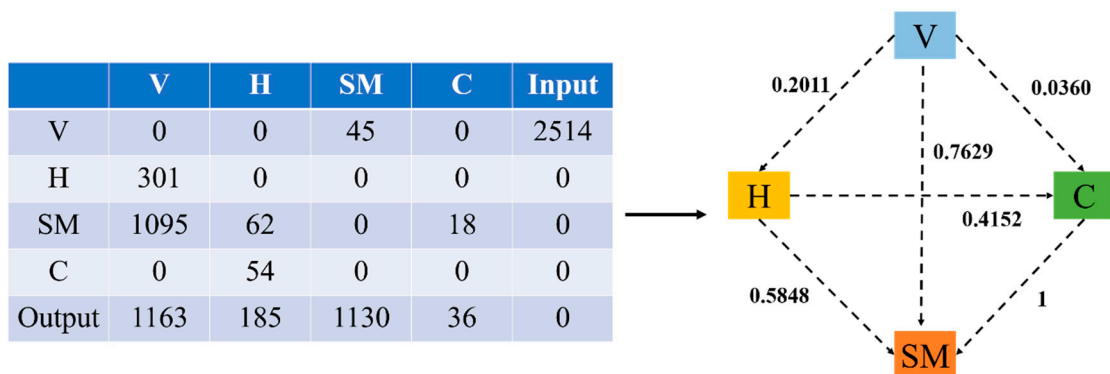


Figure S4. The energy flow matrix (F) (Kj • ft⁻¹ • y⁻¹) and control allocation (CA) calculated from this matrix among the components. (V represents vegetation, H represents herbivores, SM represents soil microorganisms and C represents carnivores.)

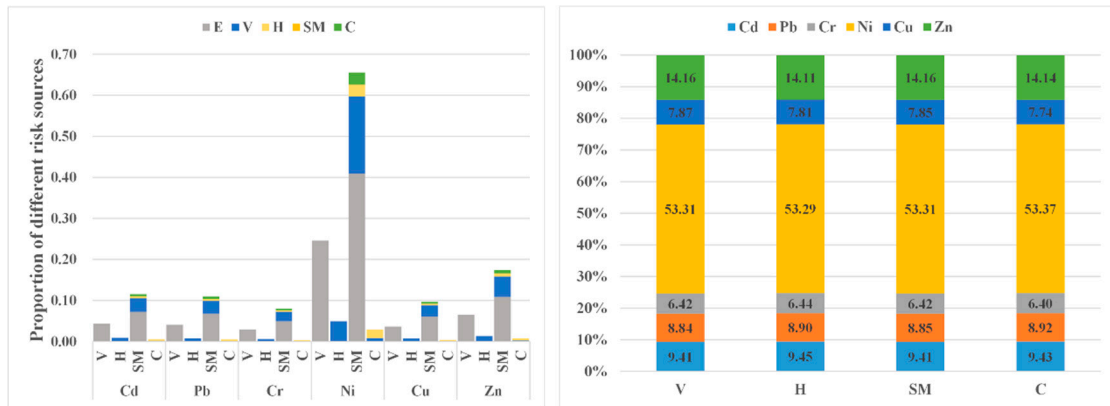


Figure S5 (a) The comparison of risks between four ecological components (including input risk from the external environment) posed by six heavy metals, (b) The proportion of risk of each heavy metal in the components.