Are threshold values for metals in soils effective for protecting the soil ecosystem?

Gerben Mol[1], Job Spijker[2], Leo Posthuma[2]

Background & Objective

- A healthy soil needs a healthy soil biocommunity. Soil threshold values for contaminants therefore need to protect the ecosystem properly.
- We developed a method to assess soil metal contamination with data from 360 locations in the Netherlands covering all major Dutch soil types.
- With the results we assessed how well threshold values for metals in soils in the Netherlands protect the soil biocommunity.

Approach

1. Reactivity of trace metals in the soil

Most studies use total metal concentrations (e.g. Aqua Regia), but the exposure of the ecosystem is determined by the reactive fraction. We estimated the reactive fraction of trace metals in soils with a 0.43 M HNO_3-extraction.

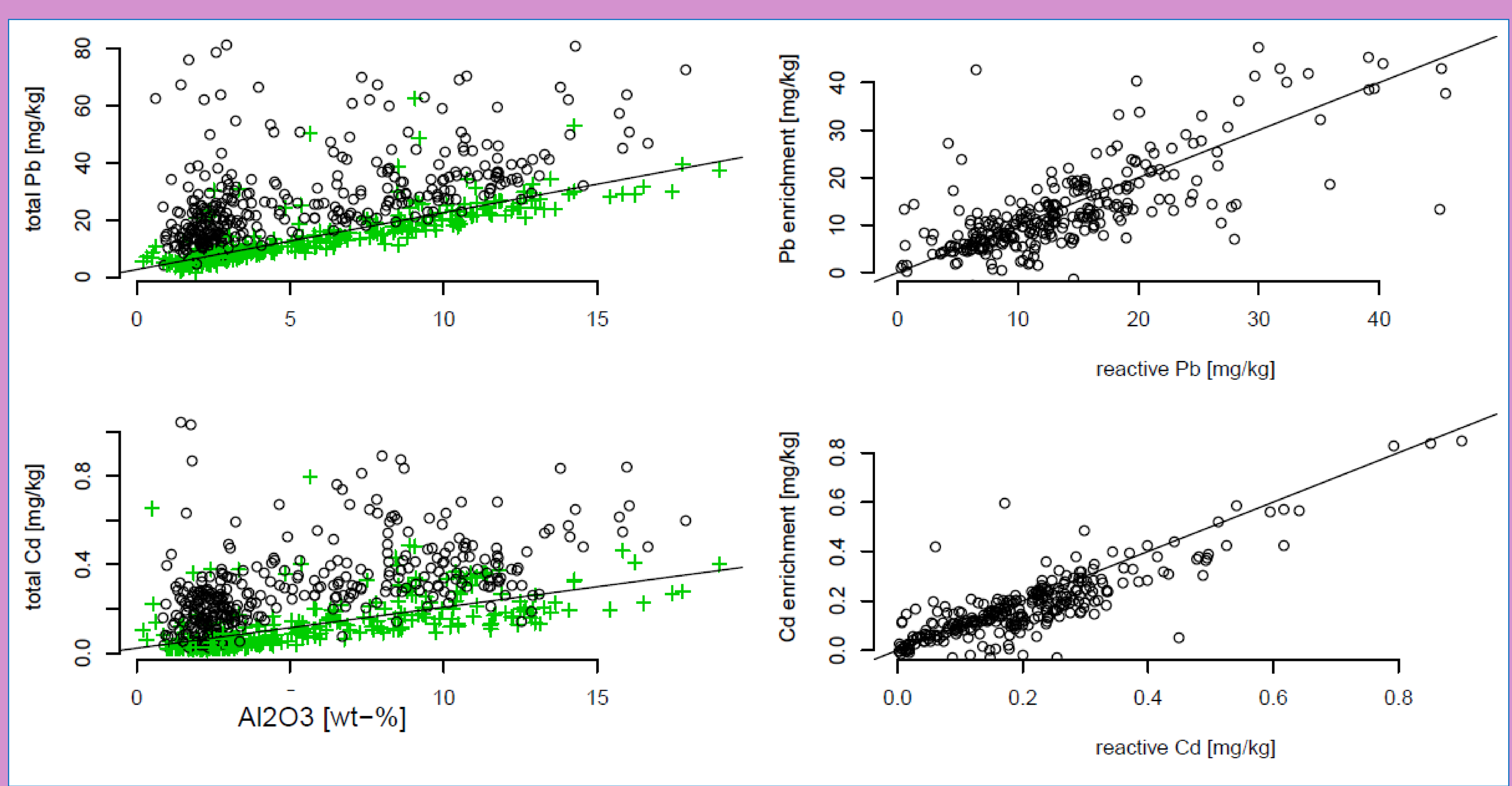

Figure 1. (***Left***) Geochemical baseline model of metal vs Al_2O_3 in subsoil (green symbols and regression line) to estimate topsoil enrichments (black circles). (***Right***) Reactive metal concentrations (0.43 HNO_3-extractable metal concentrations) vs estimated enrichments. The line depicts the 1:1 relation.

2. Species Sensitivity Distribution: the toxic pressure concept

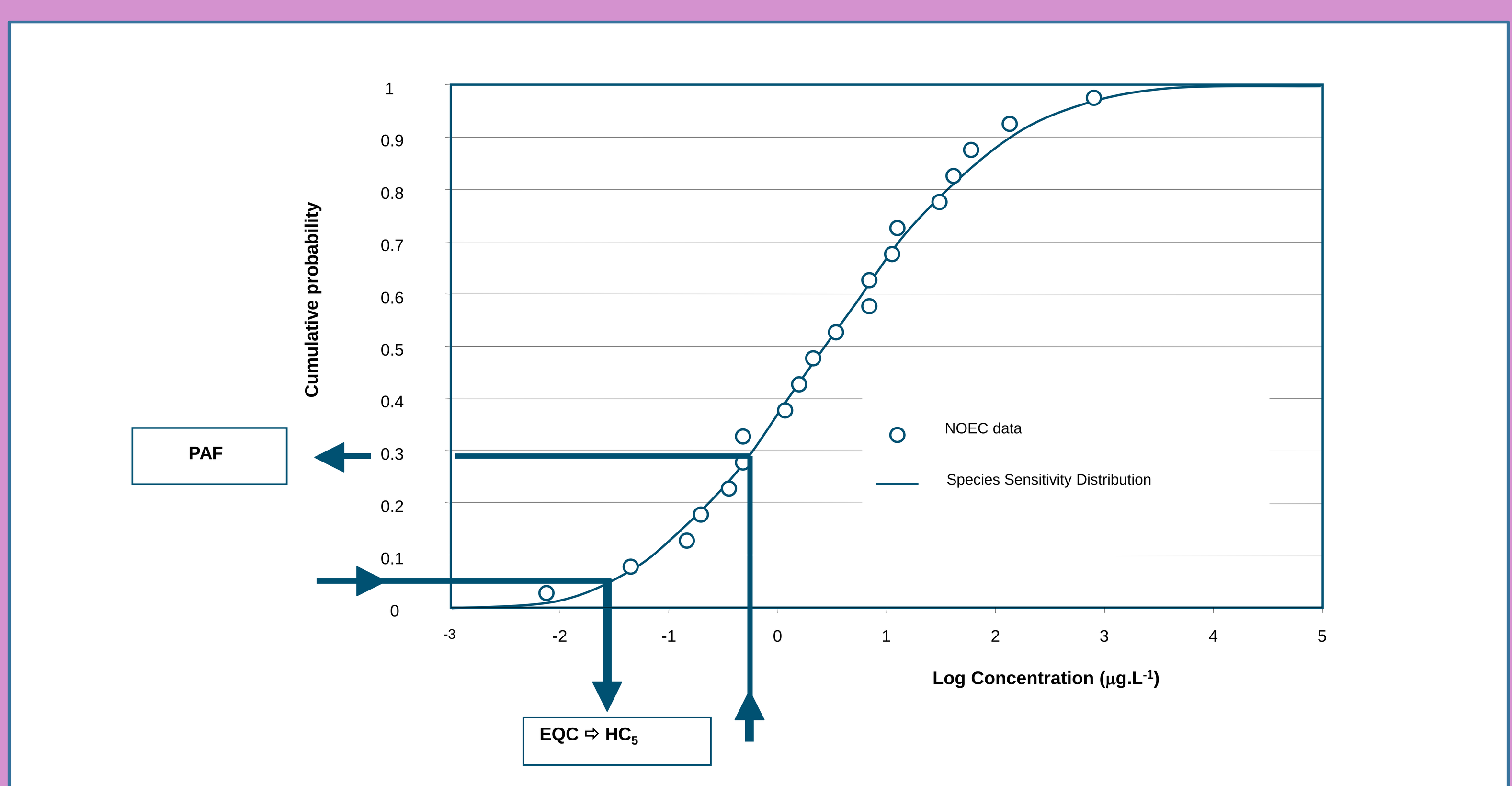

Figure 2. The concept of Species Sensitivity Distributions. X-axis: metal concentration; Y-axis: Potentially Affected Fraction (PAF) of species. EQC=Environmental Quality Criterion. HC5: Hazardous Concentration for 5% of the species. Markers: ecotoxicity data for different species. Line: the fitted SSD (often a log-normal model).

Results

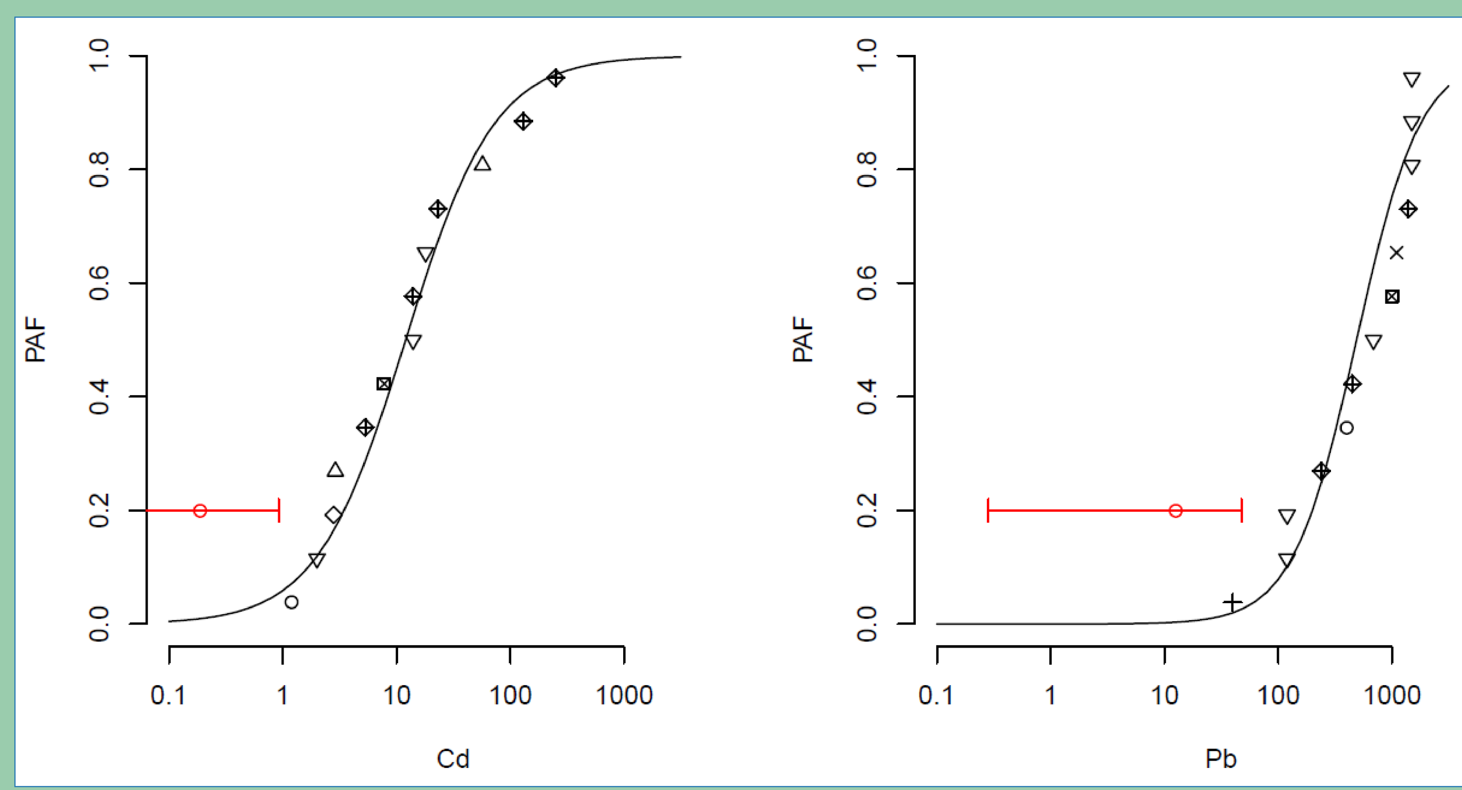

Figure 3. Species Sensitivity Distributions for Cd and Pb, based on chronic ecotoxicity data from Crommentuijn et al. (1997). The red horizontal lines refer to the X-axis only and indicate the ranges (minimum, maximum) of the measured reactive concentrations in Dutch topsoils (red circles are median values).

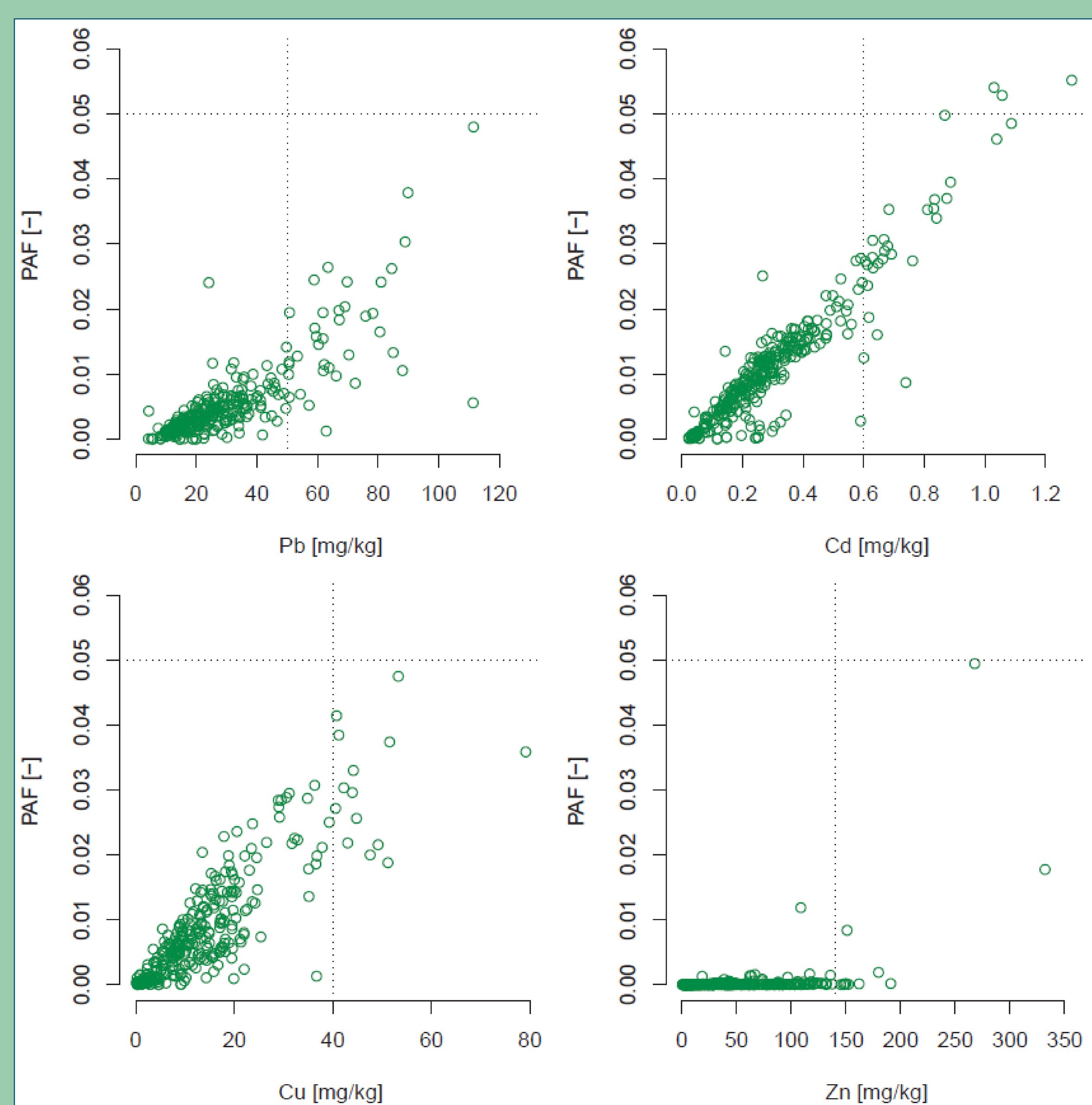

Figure 4. Total soil concentrations and toxic pressures (PAFs based on the reactive concentrations in the same samples). The horizontal lines depict the regulatory HC5 value, as derived from ecotoxicity tests with species, the vertical line depicts the soil threshold value .

Conclusions

- Ranking metals according to toxic pressure shows that Cd enrichment induces the largest hazard increase.
- Comparing soil threshold values and toxic pressures showed the thresholds to be conservative. Conservative thresholds protect the soil ecosystem properly, but do not always indicate an actual hazard or risk.
- Assessing ecotoxicity of metals based on their reactivity instead of total content provides a more refined basis for risk management decisions.

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Regional geochemical data of heavy metals are commonly used for environmental risk assessment and management. The data used are often (near) total concentrations of the elements (often determined with Aqua Regia), whereas the exposure of the ecosystem is determined by the available or reactive fraction. The objective of our research was to develop a wider applicable method for quantitative hazard assessment of anthropogenic soil metal contamination, based on and illustrated with data for concentrations of Cd, Cu, Pb, and Zn from 360 locations in the Netherlands covering all major Dutch soil types.
Extraction of soil samples with 0.43 M HNO_3 gives a good approximation of the chemical availability of metals; the metal concentration in these extracts show a strong relation to the estimated anthropogenic enrichment, so we used them to assess the hazard of human-induced enrichment of these metals. To do this we used the toxic pressure concept, which estimates the fraction of biological species that is potentially affected due to the exposure to single metals or mixtures of metals. This is done using logistic concentration/response models parameterized with ecotoxicological effect data from toxicity tests and mixture models.
Hazards varied from very low toxic pressures (lower than 0.01) to toxic pressures just below 0.05 (just staying within the so-called 95%-protection criterion used in some soil protection legislations). In rare cases, the toxic pressure exceeded the value of 0.05, to an upper limit of 0.054 for Cd. Ranking the metals according to toxic pressure suggests that Cd enrichment induces the largest hazard increase. Ranking the soil types according to their susceptibility for toxic pressure by metals only yielded minor differences in enrichment hazards between soil types. Comparing the judgement of soils based on the current soil screening levels and based on toxic pressures that we estimated in this study showed that the soil screening values tend to be on the conservative side. Conservative soil screening values do indeed protect the soil ecosystem properly, but they do not always indicate an actual hazard or risk. When screening values are exceeded, refined hazard insights can be obtained, as illustrated in this study. These insights in the ecotoxic implications of metal concentrations in soils can provide a more refined basis for risk management decisions.