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# Mass flux analysis for assessing exposure of humans to heavy metals from soils

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*Key words:* Soil pollution, heavy metals, human health, risk assessment, mass flux analysis, cadmium toxicity

## Extended abstract

Pollution by heavy metals threatens the quality of soil, so essential for life on earth. Most seriously it might eventually destroy the soil as a productive medium. However, the risk to the health of humans and other living beings by increased uptake of soil-borne heavy metals is in general more immediate. There are now many data from which to assess the toxicity of heavy metals to humans, domestic animals and cultivated plants. Dose-response relationships alone, however, are not sufficient for assessing health risks. We need also to know how exposure affects the receptors of the pollutants, and this requires a systematic analysis of pollutant mass fluxes entering the receptors. Consequently, mass flux analysis is now routinely used for the assessment of health risks due to soil pollution. If performed sensibly such analyses can give valuable informations for the detection, evaluation, treatment, and control of soil pollution problems. Uncritical use on the ohter hand can cause more harm than benefit. Resources for pollution abatement may be wasted, and wrong countermeasures may even worsen a situation. Taking the case of a residential area in Switzerland with severe soil pollution by cadmium (Geiger & Schulin 1992) as an example, the objective of this contribution was to point out merits, limitations, and potential pitfalls of the mass flux approach for the evaluation of health risks arising from exposure to the pollutant. Particular focus is given to the relevance of soil factors in this context.

The analysis for the example case started from the basic scenario of a child living in the most polluted inhabited zone of the study area, comprising approximately five hectares. For cultivated soils the total cadmium content of the topsoil (0-20 cm depth) averaged at about 4 mg/kg in this zone, whereas for non-cultivated soils peak concentrations of 14 mg/kg were measured in the topmost 2 cm (Federer 1993). It was assumed that 60% of the vegetables eaten by this child were from a garden within this highly polluted area. Values for the cadmium content of these garden vegetables were available from sample measurements, whereas values for the cadmium content of all other food, the composition of the average diet, the ingestion rate and the absorption factor were taken from the literature. According to the mass flux analysis consumption of garden vegetables as well

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as ingestion of polluted soil (accidental as well as deliberate 'soil eating') accounted each for about thirty per cent of the total cadmium uptake of the child in this scenario (see Tab. 1). The rest was attributable to uptake with other food and with beverages. The uptake of cadmium by inhalation was found to be negligible, except for smoking (see below).

| pathway<br>source | exposure<br>(kg/d) | x duration | x concentration<br>(µg/kg) | = intake rate<br>(µg/d) | x absorption factor | = absorbed dose<br>(µg/d) |
|---|---|---|---|---|---|---|
| Inhalation | | | | | | |
| smoking | 0* | 1 | 0.2+ | 0.00 | 0.25 | 0.00 |
| air | 6.5** | 1 | 0.0016++ | 0.01 | 0.25 | 0.00 |
| Ingestion | | | | | | |
| food | | | | | | |
| *garden vegetables* | 0.110 | 0.6 | 105.0 | 6.93 | 0.05 | 0.34 |
| *market vegetables* | 0.110 | 0.4 | 16.5 | 0.73 | 0.05 | 0.04 |
| *meat and fish* | 0.088 | 1.0 | 15.3 | 1.35 | 0.05 | 0.07 |
| *potatoes* | 0.057 | 1.0 | 15.0 | 0.86 | 0.05 | 0.04 |
| *grain and cereal* | 0.101 | 1.0 | 23.3 | 2.35 | 0.05 | 0.12 |
| *dairy products* | 0.270 | 1.0 | 5.7 | 1.54 | 0.05 | 0.08 |
| *fruits* | 0.234 | 1.0 | 3.0 | 0.70 | 0.05 | 0.04 |
| dust/soil | 0.0005 | 1.0 | 14000 | 7.00 | 0.05 | 0.35 |
| drinking water | 1.360 | 1.0 | 0.7 | 0.95 | 0.05 | 0.05 |
| Sum: | | | | 22.41 | | 1.13 |

* cigarettes/d　　+µg/cigarette
** m3/d　　++µg/m3

Tab. 1. Mass flux analysis for the basic scenario.

Subsequently, variations of the basic scenario were analyzed to assess the sensitivity of the estimation with respect to the uncertain values of key factors (e.g. the absorption factor) and to underlying assumptions (e.g. "clean air" assumption). This sensitivity analysis showed that passive smoking may contribute about five times as much to the cadmium load of the child as the polluted soil. The estimates were highly dependent upon the value of the absorption factor which was employed for the calculations from the range of literature values. The uncertainty of the estimated rate of direct soil uptake by children was found to be of similar importance in this analysis. Furthermore, these calculations demonstrated that using depth averages of topsoil concentrations of pollutants, as determined according to the Swiss Federal Ordinance relating to Pollutants in Soil (VSBo), can lead to serious underestimations of exposure to hazardous soil pollutants.

The large uncertainties reflect the stochastic nature of the processes as well as the inaccuracy of the data, including the absorption factors which were taken from Ohnesorge (1985) and Fergusson (1990). The ordinary mass flux approach does not account for the probability of the factors determining an exposure scenario. None the less, this approach can provide insight as it enables us to compare the relative contribution of different sources and transmission pathways of pollutants to the total risk as well as the relevance of uncertainties. Taking into account costs, it can thus serve as a useful basis for evaluating the options for managing risks, including the options for getting more information.

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