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Spatial Soil Toxicity Estimation Methodology for Improving Soil Fertility Using GIS Modeling

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Abstract

Spatial soil toxicity estimation using GIS modeling is extremely important for soil fertility improvement. For baseline ecological risk assessments, and other assessments that may lead to regulatory actions, assessors should consult the primary sources of toxicity data and then determine the applicability of the data to their specific sites. In addition, assessments should not rely on laboratory toxicity data only. Where toxicity to soil invertebrates is suspected, toxicity tests should be performed with the contaminated soil. In addition, the abundance of earthworms in the soil of a particular site, determined during collection of earthworms for chemical analysis, may provide a rough indication of the likelihood of soil toxicity. During the course of the investigation, the landowner needs to be aware of the risks the site may pose and, where necessary, restrict access to the site until the risks are mitigated to an acceptable level.

Keywords: Soil toxicity; fertility; GIS; assessment; management.

1. Introduction

Damaged soil ecosystems were best identified by comparison of their profiles to the profiles of closely matched reference soils, rather than by comparison to these absolute values. The presence or absence of earthworms offered a partial explanation of observed differences in soil organic matter profiles [1]. The ability of soil to respond to a toxic waste clearly differed after a period of exposure to the waste. The faster response was probably related to the increased pool of stabilized organic matter present in soil, arising from the stabilization of added olive waste in the soil [2]. Total concentrations of metals in soil are poor predictors of toxicity. In the last decade, considerable effort has been made to demonstrate how metal toxicity is affected by the abiotic properties of soil. The corrections for ageing and for modifying effects of soil properties in metal salt amended soils are shown to be the main factors by which predicted no effect concentration (PNECs) values rise above the natural background range [3]. Toxicity testing is a well-established science for comparing the hazard of one chemical to another, or for assessing the hazard of chemicals, singularly or in mixtures, to a particular test organism(s) [4]. Artificial soils are particularly useful when the comparison of two or more chemicals or sites is desired or when a chemical has been, or is anticipated to be, released into the environment at known concentrations, for example, at pesticide label registration rates [5-6].

2. Investigation Objectives

The first step is to identify the purpose of an investigation and set investigation objectives accordingly. There are many reasons why a local authority or landowner may want to investigate a former sheep-dip site, including concern that the site represents a risk to the landowner/occupier, employees or wider public; potential environmental liabilities need to be determined in order for a site to be sold, purchased or redeveloped; the land is proposed to be rezoned and a change in land use will take place in the near future; concern that the site represents a risk to crops, livestock or meat quality, or that it may have effects on the terrestrial ecosystem (bacteria, bugs, animals and plants); a down-gradient water source has high concentrations of dip contaminants. Identifying the issues to be resolved will help to establish clear sampling objectives for the investigation which define why or how samples are being collected. In the context of sheep-dip sites, a common sampling objective will be to establish the nature, degree and extent of contaminant distribution (both vertically and laterally). With regard to off-site effects, locating the sources of contamination will be the first step.

3. Conceptual Model

Once the objectives for the investigation have been determined, readily available data should be reviewed. Structural evidence or anecdotal information gathered during the identification phase will be useful to include in the data collection. Other sources may include old records of the site, or previous investigation reports. Based on the existing data, a conceptual model of potential exposure pathways needs to be developed. Experienced contaminated land consultants are usually contracted to develop the conceptual model, set the data quality objectives (such as sampling density and requirements for validation sampling), and carry out the site investigation and sampling. It will be beneficial to both sides if the landowner or council and the consultant work together closely in developing the conceptual model. The model should identify the exposure pathways, including contaminant sources (eg, previous sheep-dip location, chemical storage location and methods used to dispose of chemicals, and the likely depth of soil contamination); transport mechanism or exposure route (eg, drinking contaminated water); receptors (eg, a nearby surface-water body, groundwater well, farm workers, animals). The model can be improved by gathering additional data, such as from a geophysical survey, an aerial photograph or specialised remote-sensing techniques (eg, Landsat satellite false colour image, or side-scanning radar). Due to the complexity associated with each individual site, a summary of the recommended procedures for three site scenarios is needed. Each scenario specifies the recommended way of sampling, assessment of results and selection of remediation options.

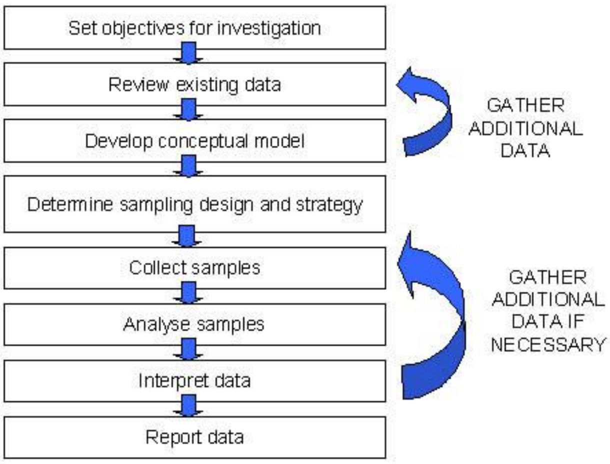

Figure 1: Recommended approach to a site investigation.

4. Sampling Design and Strategies

The sampling programme is developed using the conceptual model. Visual inspection of a site, examination of photographs and maps, and information from local residents can be used to determine the best location for sampling points within an area of investigation. A site assessment may include an investigation of the soil at the site, and of groundwater and surface water within the vicinity of the site. For example, a disused sheep-dip site may contain a permanent concrete trench and an area of soil through which contaminants seep and discharge into a nearby stream. In this case, it will be necessary to sample the dipping vat and adjacent soil and water, soil and sediment in the seepage zone, surface water, and sediments. Other possible sampling sites within an old sheep-dipping site may include: soil beneath the dip bath and within the bath; soil in the splash zone around the dip; soil in the disposal/run-off area where sludge and spent dipping chemicals may have been disposed of, and drainage to where the spent or discharged liquid dip flowed; soil from yards where freshly dipped sheep were collected before further transport; soil in the storage area for chemicals, and soil beneath the woolshed; water from one or more areas of the identified site; water from one or more groundwater wells in the area; water and sediment from one or more areas of a seepage zone; water and sediment from one or more areas of a stream or foreshore. It was found that the systematic sampling approach provides current best practice for assessing contamination at old sheep-dip sites.

5. Sample Collection and Data Interpretation

The aim of sampling is to identify the three-dimensional extent of any contamination that exceeds the soil guideline values. The sampling results will provide important information for the development of a remediation plan. When collecting soil samples from an undisturbed sheep-dip site (eg, no previous clean-up, no placement of fill nor development), shallow sampling (0 to 15 cm) may be sufficient to determine the horizontal extent of contamination. For disturbed sites, sampling at varying depths may be required to establish the horizontal extent, because fill material may cover the contamination. Soil samples should be collected at the depth where contamination is most likely to occur based on known site conditions. Soil samples need to be collected from inside the base of the sheep-dip bath, and in the natural material underlying any soil back-fill. Soil samples should also be collected within the surface soil of the splash zone and from the exit zone of the dip, in the vicinity of the draining platform or holding pens, and from the area where the sheep-dip chemicals were stored and the spent dipping fluid disposed. Careful sampling procedures need to be used because the actual amount of soil or water analysed by the laboratory is extremely small.

Depending on the purpose of the investigation, it may be appropriate for the soil profile to be classified during soil sampling and a soil log produced to ensure that soil samples are collected at the appropriate soil horizons (eg, within any fill material and in the natural underlying soils). Based on the sampling design, the location of each sample point should be recorded on a site plan, with reference to permanent features and structures, if possible. Sample points or dip features can be recorded accurately in the field using a GPS mapping system. Usually an experienced contaminated land practitioner or consultant is employed to carry out the sampling. The first step in interpreting analytical results of samples collected from various locations around the site is to examine them for patterns that identify the likely nature and spread of contaminants. The results of chemical analysis of samples taken from soil, sediment or water are typically compared with guideline values to assess whether a site is contaminated. This assessment forms the basis for deciding if further investigations are required, or which remediation or risk management options are feasible for the site. This subsection provides a review of relevant guideline values and how they might be applied. Appropriate soil guideline values may include those developed to provide protection for receptors living on the site (eg, people, worms, plants) or off the site (eg, fish, algae).

Soil guideline values are soil concentrations that are protective of people or ecological receptors, and they are based on generic exposure scenarios. More specifically, for the protection of human health, soil guideline values are derived by defining some critical receptor (eg, a child of certain age and weight) and defining a tolerable daily intake for that receptor for the particular contaminant. Then, using assumptions for exposure (eg, duration, exposure pathway), the soil concentrations that would equal the acceptable daily intake for the assumed exposure are calculated. As a result, the selection of an appropriate soil guideline value must consider the proposed or current land use. For example, if the site is to be developed for general residential use, the results should be compared to a residential value for protecting human health. For ecological receptors, soil guideline values are developed to provide a certain level of protection for terrestrial species (plants, soil invertebrates and wildlife) and soil microbial functions. Such guideline values are considered to be most applicable to land uses where a functioning ecosystem is desirable. Soil guideline values for the protection of on-site ecological receptors could also be used to provide target values for long-term soil quality. Consideration should also be given to the protection of off-site receptors such as surface water and groundwater.

6. Site Specific Risk Assessment

Site-specific risk assessment is useful for establishing the risk posed by contaminants to people, livestock or ecological receptors currently present on the site. It focuses on modifying the actual exposure of those receptors (eg, time spent on the site, activities occurring). However, where future use of a site is being considered, a given exposure scenario is assumed for a particular land use and there is no basis for modifying the exposure parameters. It would be appropriate to undertake a site-specific risk assessment if meat, milk or eggs from livestock raised on lifestyle blocks are being consumed by residents on those sites, because organochlorine compounds such as DDT and dieldrin are known to bioaccumulate in the food chain. In addition, site-specific risk assessment would be appropriate for the commercial/ industrial land-use category where paving has been used as a means of reducing exposure to on-site contaminants. Site-specific assessments may also be relevant where the naturally occurring concentrations of chemicals exceed the relevant guideline values.

7. Reporting Data and Requirement

The following checklist (Table 1) outlines the sections that should be included in a detailed site investigation report of a disused sheep-dip site. This information should be collected by a local authority when they are involved in investigations into former sheep-dip sites (eg, during subdivision or change in land use, or otherwise according to rules in a plan). The information contained in this subsection summarizes the information that is important for contaminated land management guidelines.

Table 1: Checklist of reporting requirements.

Report section	Procedure/ inventory
Executive summary	Background; Objectives; Scope of works; Summary and conclusions
Scope of works	Clear statement of the scope of the works
Site identification	Site address; Legal description; Geographic coordinates; Site plan; Locality map
Site history	List of site owners, including both previous landowners/occupiers and current landowners/occupiers, and previous and current land uses; List of contaminants of concern; Zoning (present and proposed); Location of ground- and surface-water bodies; Location of relevant sheep-dip structures; Anecdotal information regarding the site, where possible; History of the neighbouring property and site usage; Review of aerial photographs, where appropriate
Site conditions	Topography; Soil; Geology; Hydrogeology; Observations, including site vegetation; Access/risk potential - people, livestock, produce, ecosystems
Sampling and analyses plan	Sampling and analytical data objectives; Rationale for sampling pattern, sampling number and analysis programme
Basis of guideline values	Table indicating guideline values used; Assumptions and limitations of guideline values
Results	Site plan showing sample locations and exceedances of guideline values; Tabulated results showing guideline exceedances and other statistical information
Conclusions and recommendations	Brief summary of the results; Assumptions and uncertainties; Recommendations for additional works (if required); List of appropriate site uses

8. Conclusion

GIS based approach can be an important step in ecological risk assessments for screening the chemicals occurring on a site for contaminants of potential concern. Screening may be accomplished by comparing reported ambient concentrations to a set of toxicological benchmarks. Multiple endpoints for assessing risks posed by soil borne contaminants to organisms directly impacted by them have been established. Chemicals that are found in soil at concentrations exceeding both the benchmarks and the background concentration for the soil type should be considered contaminants of potential concern. Situation-specific information would be the best guide to setting metal pollutant loading limits on agricultural land. Detailed knowledge of the soil at the application site, especially pH, CEC, buffering capacity, organic matter and clay content, is essential. Soils with little capacity to buffer pH and adsorb metals are poor candidates for metal-contaminated waste application. There is need for further research and application of innovative ideas and procedure for soil toxicity estimation.

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