Bioaccessibility of potentially harmful soil elements

Mark Cave outlines in-vitro methods that are reducing the costs of assessing the human health risks of soils.

Quantitative guidelines for assessing risks from potentially harmful elements in soil are associated with several scientific problems. There are difficulties in establishing concentrations of contaminants beyond which risks from exposure to these contaminants would be unacceptable. This requires not only scientific (toxicological) information on the health effects, but also an element of judgement on what is unacceptable risk. In addition, soil is only one of the sources of contaminant exposure, and its effect, and the cost of dealing with it, needs to be kept in proportion with the total exposure to contaminants from all sources.

Whether contaminated soils pose a human health risk depends on the potential of the contaminant to leave the soil and enter the human bloodstream. In terms of human health risk assessment there are three main exposure pathways for a given contaminant present in soil. The largest area of concern is the oral/ingestion pathway, followed by the dermal and respiratory exposure routes[1].

There is, therefore, a clear need for a practical methodology that measures the fraction of the contaminant in the soil that, through oral ingestion, can enter the systemic circulation of the human body and cause toxic effects. This is known as the oral bioavailability and can be formally defined as the fraction of an administered dose that reaches the central (blood) compartment from the gastrointestinal tract[1]. This is distinct from the oral bioaccessibility of a substance, which is defined as the fraction that is soluble in the gastrointestinal environment and is available for absorption[1].

The use of total contaminant concentrations in soils provides a conservative approach as it assumes that all of the metal present in the soil can enter the bloodstream. Results from animal tests[2] suggest that contaminants in a soil matrix maybe absorbed to a lesser extent and show fewer toxic effects compared to the same concentration of soluble salts of the contaminants in a food or liquid matrix. In many cases there is no distinction made between the intake for contaminants that are bound to soil and those which occur as a vapour or are released during processes like digestion into solution (the bioaccessible fraction). For example, children may ingest arsenic-contaminated soil by eating soil or putting dirty hands or soiled toys in their mouths. Empirical studies have sought to demonstrate a relationship between the type of contaminated soil and the fraction of arsenic that can be dissolved by digestion[3]. Using such studies may improve our knowledge of the intake of bioaccessible organic and inorganic compounds in the future, as this parameter represents a better estimate of exposure than total concentration of soil contaminants.

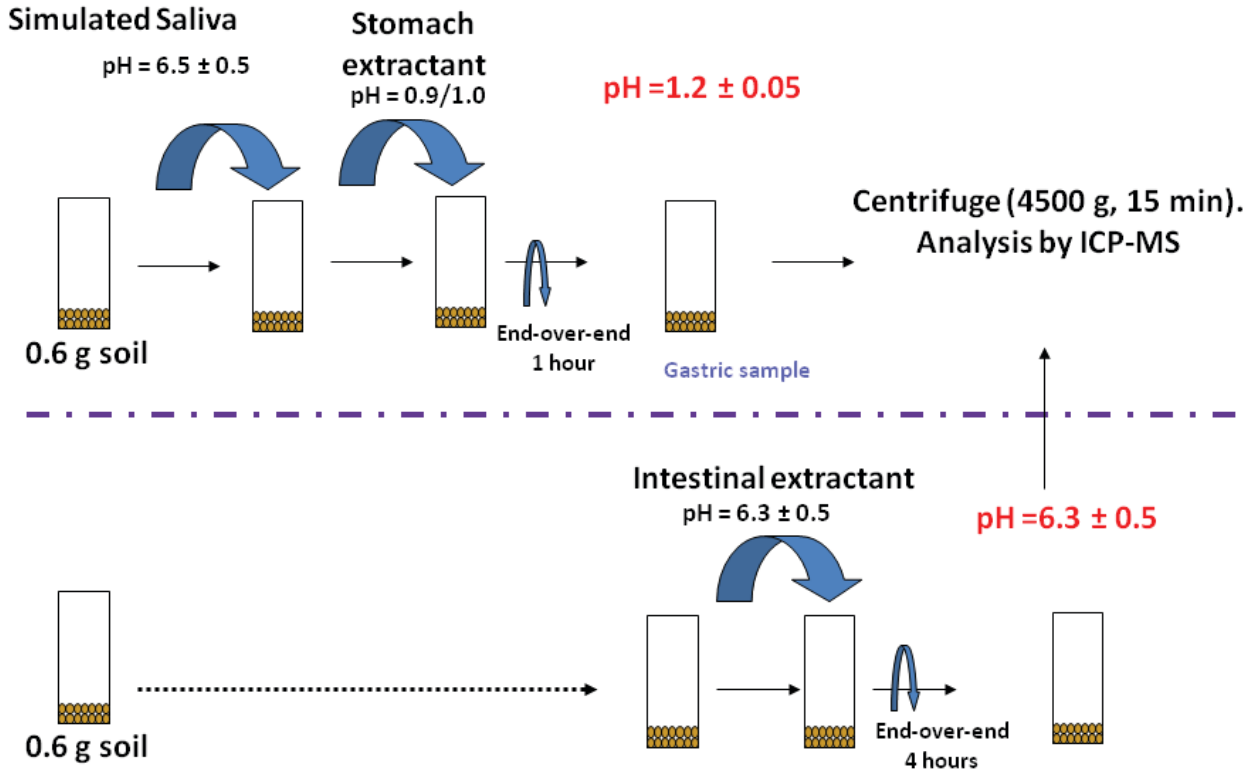
IN-VIVO AND IN-VITRO METHODS

Since bioavailability data is essentially related to the amount of contaminant in the animal/human bloodstream, the data must be produced from the dosing of animals with contaminated soil and the subsequent measurement of the contaminant in the blood or organs of the animal; these are known as in-vivo animal models. Bioaccessibility data, however, is normally determined in a test-tube environment (in vitro) and represents the amount of contaminant dissolved in the gastrointestinal

tract prior to crossing the mucosal walls. The amount of pollutant that is actually absorbed by an organism is generally less than or equal to the amount that is mobilised[1]. In-vivo dosing trials have used a variety of animal species such as rats and rabbits, but species that have similar gastrointestinal tract characteristics to human children, such as immature swine, are preferred and have been shown to be reasonable analogues for children[4]. In this type of testing, known amounts of contaminant are added to the feed of the species being tested, in the form of soluble salts or contaminated materials. Bioaccessibility extraction tests are generally based around the gastrointestinal parameters of young children of up to three years of age, since they are thought to be most at risk from accidental ingestion of soil. Also, since children can absorb a higher percentage of contaminant through the digestive system than adults, they are more susceptible to adverse health effects[5].

Mammal dosing trials are time-consuming and expensive. To supersede the use of animals in determining the bioavailability of potentially harmful elements for human health risk assessment, or to estimate bioavailability where animal studies are not available, a potential alternative is the use of in-vitro tests.

In-vitro testing regimes are used as predictors, as they do not provide absolute bioavailability data, since this can only be done at present by in-vivo techniques. As the cost and time required to perform in-vitro techniques is small in comparison to in-vivo methods, a larger number of soils can be assessed to fully characterise a site. A number of in-vitro bioaccessibility tests for mimicking human ingestion have been reported in the literature and have been comprehensively reviewed[6,7]. Of these, there are four batch extraction methods that are most commonly used: the physiologically based extraction test (PBET) originally developed by Ruby *et al*. (1996)[3]; the in-vitro gastrointestinal method (IVG)[8]; the Dutch National Institute for Public Health and the Environment method (RIVM)[6,9,7] which is mainly used in Europe; and the relative bioaccessibility leaching procedure (RBALP) which was developed specifically for lead in soils[10]. The PBET, IVG, and RIVM methods use extraction media that closely mimic the chemical environment of the human gastrointestinal system, i.e. they are physiologically based, whereas the RBALP uses the physiologically relevant pH of the stomach but uses a glycine buffer as the extraction medium. As a result of research carried out by the Bioaccessibility Research Group of Europe (BARGE) and other research groups, it was clear that the different bioaccessibility tests showed similar trends when used on the same soil samples, but the different operating conditions for each test produced wide-ranging bioaccessibility values between the methods[11]. To overcome this problem, BARGE took a joint decision to progress the development of a harmonised in-vitro bioaccessibility method (the unified BARGE method – UBM)[12] as seen in **Figure 1**.



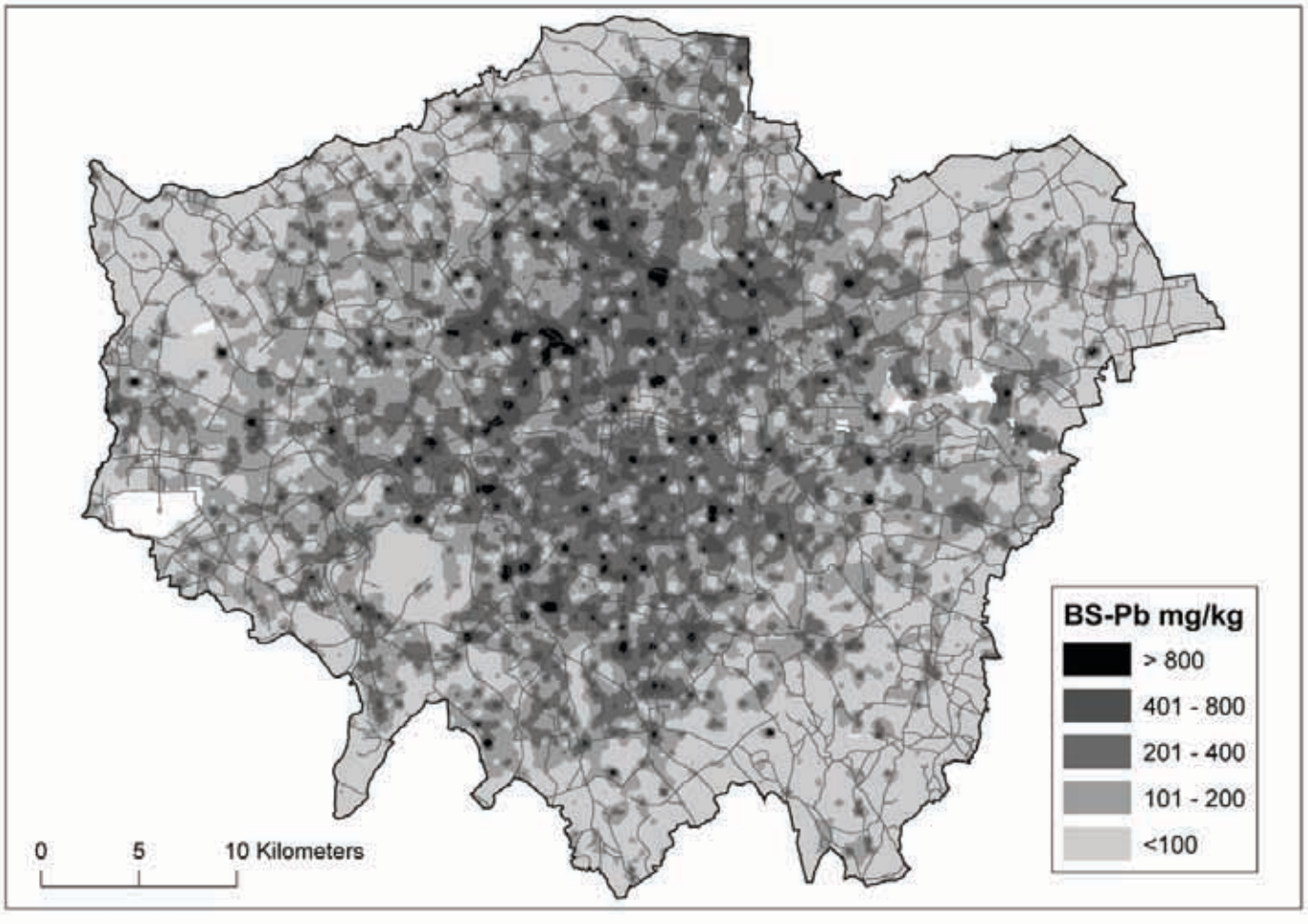
▲ **Figure 1. Schematic outline of the BARGE unified method**

The main criteria for the test were:

- it should be physiologically based, mimicking the human physico-chemical environment in the stomach and small intestine. This should help to obtain good agreement with in-vivo data and enhance public understanding of the test;
- it should represent a conservative case;
- there should be one set of conditions for all potentially harmful elements (PHE) being studied;
- it must be demonstrated that the test is a good analogue of in-vivo conditions; and
- the test must be able to produce repeatable and reproducible results within and between testing laboratories.

The chosen method was the RIVM method[9] as this was considered to be the most suitable static or batch method available, and therefore more likely to be adopted by testing laboratories. The RIVM methodology has also gained acceptance by regulators in both the Netherlands and Denmark. Modifications were made to the RIVM methodology to ensure adequate conservatism and that the in-vitro test was robust and applicable to the different soil types found in a range of different countries. A schematic outline of the method is shown in **Figure 1**.

The UBM has now undergone initial inter-laboratory trials[13] and been validated against an in-vivo model[2]. It has become widely accepted as the method of choice in European countries.



▲ **Figure 2: Estimated bioaccessible lead in topsoils in the Greater London area; solid lines indicate roads (Source: Ordnance Survey Strategic data © Crown copyright 2012)[16]**

WIDER IMPACTS OF MEASURING BIOACCESSIBILITY

In a study of the financial impact of research carried out for the NERC (Natural Environment Research Council) by BGS (the British Geological Survey)[14], examples of the use of bioaccessibility testing were given that showed that:

- in one case the assessment enabled the re-use of existing site materials as part of the land-remediation process, which subsequently led to reduced costs of approximately £3.75 million. In addition, approximately 3,750 lorry trips to landfill were avoided and 105 tonnes of carbon-dioxide equivalent were saved; and
- in another example, BGS worked with Land Quality Management and University of Nottingham staff to save between £7 million and £30 million in remediation expenses on one site. The more accurate bioaccessibility testing not only reassured local residents, but also allowed the stalled housing market in the area to restart.

Across England, there are an estimated 15,470 ha of land in need of remediation. The cost of remediating this land is between £100,000 and £325,000 per ha, giving a potential market of £1.5 billion to £5.0 billion.

The research methods developed by BGS have the potential to save between £3.9 million and £12.6 million per year in remediating derelict land for development. Over a 20-year period, these cost savings are estimated to have a Net Present Value of between £55 million and £179 million.

The method is also being used on a national scale to provide bioaccessibility maps for arsenic and lead[15,16]. **Figure 2** shows an example of how a combination of the UBM test and data modelling has produced a map of the bioaccessible lead in soils in the Greater London area.

Bioaccessibility testing cuts across a number of disciplines including chemistry, geochemistry, toxicology, human health and risk assessment, and recent collaborative work untaken by research consortia such as the BARGE group have enabled the development of standardised testing protocols that have had a direct impact on human health risk assessment and demonstrable economic benefits when used on a national and international scale. ES

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