RECOVERING CONTAMINATED SOILS THROUGH PHYTOMANAGEMENT IN SOUTHWEST EUROPE

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Guide best practices for phytomanaging metal(loid)-contaminated soils :

GT1 Characterization and risk assessment of contaminated/ degraded sites and implementation of suitable phytomanagement options

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Highlights

• Assess main topics of metal(loid)-contaminated/degraded soil (phyto)management helping to take decisions;

• Contribute to best practices for (phyto)managing metal(loid)-contaminated soils based on risk management strategies;

• Guide can be used as example for Europe (e.g. SUDOE region) and other countries;

• Provide case studies located in Nouvelle-Aquitaine (France), Spain and Portugal (SUDOE region);

• Provide sustainable gentle (phyto)remediation options for rehabilitating/enhancing the usability and economic value of (marginal) land contaminated/degraded by metal(loid)s.

Abstract

Gentle remediation options (GROs) are risk management technologies involving plant (phyto-), fungi (myco-), and/or bacteria-based methods that result in a net gain (or at least no gross reduction) in soil functions and effective risk management.

GROs can be customized along contaminant linkages for generating a range of wider economic, environmental and societal benefits in contaminated/degraded land management.

The application of GROs as practical on-site remedial solutions is developing notably in Europe and for metal(loid)-contaminated soils. Case studies (n = 8) are reported for the EU SUDOE region.

This document provide decision support tools and practice guidances developed for the practical adoption of GROs in contaminated land management, notably updated by the EU-funded PhytoSUDOE project and a network of long-term field trials at 8 sites located in France, Spain and Portugal. It is in continuity of the Model Procedures for the Management of Land Contamination, Contaminated Land Report 11 (Environment Agency UK, 2004; 2010), SUMATECS and Greenland documents.

GENERAL INTRODUCTION

Phytomanagement of contaminated soils - an overview

- **Phytomanagement and phytotechnologies**

Metal(loid)s (trace elements, TE), mineral oils (e.g., diesel fuel) and polycyclic aromatic hydrocarbons (PAHs) are among the most widely spread contaminants affecting European top-soils (Panagos et al. 2013; van Liedekerke et al. 2014). These are also what regulators are looking for first. Xenobiotics such as organochlorines, paraquat, glyphosate or similar compounds and their derivatives are probably subject also to a widespread diffuse contamination. Activities such as mining, metallurgy, electronics, agriculture and the use of fossil fuels discharge a considerable amount of metal(loid) contaminants into soils, whilst accidental spills of petroleum-based products used for transportation (typically diesel-type fuels) are the principal cause of contamination with organic compounds (Barrutia et al. 2011). Soil contamination is often more complex since these contaminants frequently occur simultaneously (Agnello et al. 2016).

Over the last few decades various Gentle soil Remediation Options (GRO) have been developed to (phyto)manage contaminated soils (Kidd et al. 2015; Mench et al. 2010; Mench et al. 2009; Mench et al. 2018; Vangronsveld et al. 2009). GRO include *in situ* stabilisation ("inactivation") and plant-based ("phytoremediation") options. Conventional methods of remediation are based on civil engineering techniques (e.g. encapsulation, vitrification, soil washing, etc.) which have a high environmental impact (destroying soil structure and function) and elevated cost. GRO offer alternatives, which are considered to be less invasive, more cost-effective and more sustainable.

Phytoremediation was initially proposed (early 1990s) as plant-based methods to remediate contaminated environments, and alternatives to conventional civil engineering-based techniques. In the case of organic pollutants, plants and their associated microorganisms are used to degrade the contaminants to non-toxic metabolites, either within the plant tissues (phytodegradation) or in the root-soil interface or plant rhizosphere (due to microbial activity or release of enzymes from plants: rhizoremediation). In TE-contaminated sites, GRO aim to decrease the labile ("bioavailable") pool and/or total content of metal(loid)s in the soil through their uptake and accumulation in harvested plant parts (e.g. phytoextraction), or to progressively promote *in situ* inactivation of TE by combining the use of TE-excluding plants and soil amendments (e.g. phytostabilization). Both strategies have been subject to much discussion regarding their intrinsic limitations, such as the long time required to effectively extract metal(loid)s from medium to highly contaminated sites (although this can be overcome by considering "bioavailable contaminant stripping"). As a result, the concept of phytomanagement evolved which combines sustainable site management with gentle remediation options leading to the reduction in pollutant linkages alongside the restoration and/or generation of wider site services ((Burges et al. 2018; Cundy et al. 2016). Phytomanagement approaches promote the use of gentle remediation options (based on the interaction between plants, microorganisms and soil amendments) within an integrated, mixed, site risk management solution or as part of a “holding strategy” for vacant sites. The use of profitable plants and the manipulation of the soil-plant-microbial system can control the bioavailable pool of soil contaminants, while maximizing economic and/or ecological revenues but minimizing environmental risks. Potential benefits include water runoff/drainage management, green space provision, soil erosion prevention, renewable energy and material generation, restoration/rehabilitation of plant, microbial and animal communities, greenhouse gas mitigation and carbon sequestration, recovery of land values, amenity and recreation, etc. (Cundy et al. 2016; Evangelou et al. 2015; Kidd et al. 2015; Simek et al. 2017; Touceda-González et al. 2017a; Touceda-González et al. 2017b; Xue et al. 2018).

In recent years, phytomanagement has moved from a bench-scale level to full-scale deployment in the field. However, the long-term effects of various soil phytomanagement options on soil functionality, biodiversity, ecological functions and ecosystem services have been poorly assessed and reported. The objective of the PhytoSUDOE project was to increase our understanding, and to provide evidence from long-term field sites, of the effects of phytomanagement on soil functionality and provision of ecosystem services.

The GT1 was assessing the occurrence and extent of pollutant linkages at each site, summarizing them in a conceptual model, then the feasible gentle remediation options based on phytotechnologies and finally the efficiency of implemented GRO regarding the residual risks and pollutant linkages.

- **Phytomanagement options**

Gentle remediation options (GRO) have been developed as eco-friendly alternatives to traditional, civil-engineering methods of soil remediation (Kidd et al. 2015). These remediation options include *in situ* stabilization (inactivation) and plant-based (generally termed as phytoremediation) options, and are addressed to decreasing the labile (bioavailable) and/or the total content of contaminants (Cundy et al. 2016). These techniques are mainly based on the use of plants, soil microorganisms and amendments, also aided by agronomic management, which effectively reduce pollutant linkages while preserving the soil resource and remediating ecological functions (Vangronsveld et al. 2009). The use of contaminated land for the production of valuable biomass (such as the production of timber, bioenergy crops, biofortified products, ecomaterials, etc.) falls within the concept of phytomanagement (Robinson et al. 2009) and is considered essential for the commercial success of these phytotechnologies (Conesa et al. 2012). The guides which have been produced as part of the PhytoSUDOE project are based on experiences in metal(loid)-contaminated soils.

Different options for the phytomanagement of contaminated soils are described below:

- Phytostabilization uses tolerant plant species with a TE-excluder phenotype to establish a vegetation cover and progressively stabilize and/or reduce the availability of soil pollutants (Dary et al. 2010; Mench et al. 2006; Ruttens et al. 2006a; Ruttens et al. 2006b; Vangronsveld et al. 2009). The incorporation of amendments into the soil or use of microbial inoculation (aided phytostabilization) (Mench et al. 2010) can further decrease the bioavailability and phytotoxicity of pollutants located in the root zone, while improving plant establishment. Phytostabilization does not lead to the actual removal of contaminants but reduces pollutant bioavailability and transfer to other environmental compartments. The mechanical action of the plant roots reduces soil erosion and transport of soil particles through natural agents, while evapotranspiration minimizes leaching during the growing season and therefore contaminant dissemination. In addition, the adsorption, precipitation, and accumulation of the contaminants in the rhizosphere (in collaboration with microorganisms associated with plant roots) entail their immobilization (Mench et al. 2010).

Fitoestabilización

- Phytoextraction is based on the use of TE-tolerant plants that take up contaminants (in general two or three metal(loid)s, rarely more) from the soil and accumulate them in excess in their harvestable aboveground biomass as compared to their common ranges (Vangronsveld et al. 2009). Phytoextraction can be aided

Fitoextracción

by soil amendments, chemical agents and soil microoroganisms (aided phytoextraction). When marketable TE (such as Ni, Au, etc.) are recovered from the plant biomass (bio-ores) it is known as phytomining (Chaney et al. 2007). Another option is to pyrolyse / calcine such metal(loid)-rich biomass and to use the biochar or ashes as ecocatalysts in the biosourced fine chemistry (Clavé et al. 2016; Escande et al. 2014).

• Phytovolatilization exploits the ability of plants to transform pollutants into volatile compounds either outside or inside some plant parts after uptake or to absorb and transport volatile compounds from the soil to the aboveground biomass where they can then be released to the atmosphere (Wenzel 2009). When the contaminant is transformed and released directly from the soil surrounding plant roots (rhizosphere), it is usually termed as rhizovolatilization (Zhang and Frankenberger 2000).

• Phytodegradation or phytotransformation uses plants (and their associated microorganisms) to degrade organic contaminants to non-toxic metabolites having at their concentrations less or no toxic effect (Weyens et al. 2009). When the degradation takes place in the rhizosphere of plants (due to microbial activity or release of enzymes from plants), terms such as phytostimulation or rhizodegradation are more correct (Becerra-Castro et al. 2013).

• Rhizofiltration is based on the use of aquatic plants to absorb in and/or adsorb on their roots the contaminants present in water, sediments or aqueous wastes in their roots. The use of aquatic macrophytes as biofilters in natural and constructed wetlands and wastewater treatment facilities has gained interest due to their well-known bioaccumulation properties (Marchand et al. 2010; Salem et al. 2014).

- **Advantages and constraints**

The remediation of contaminated soils by phytotechnologies is considered an environmentally-friendly, aesthetically pleasing and economically viable alternative to harsher civil engineering-based methods. Moreover, phytomanagement can be applied *in situ* and on a large scale. Establishing an extensive plant cover prevents the dispersion of contaminated soil particles by wind and/or water erosion and can decrease contaminant availability and mobility through root accumulation, rhizosphere-induced adsorption and precipitation and/or degradation (Vangronsveld et al. 2009). However, these techniques do of course present a series of limitations and still require optimization before they can become fully implemented on a wide-scale. In addition to the inherent problems associated with any agronomical practice (such as the dependence on climate and season, outbreaks of pests or disease, etc.), a major problem associated with these techniques is the length of time required for the clean-up process (of particular concern in phytoextraction). Several authors have suggested that to be realistically viable the clean-up time should not exceed 10 years (Robinson et al. 2009; Vangronsveld et al. 2009). The time length required can also be significantly reduced if the target values are based on the available pool of contaminants and the pollutant linkages instead of total soil contaminant concentration. As mentioned above, the shift from phytoremediation strategies to phytomanagement options, in which remediation strategies are combined with sustainable site management options, result in a net gain (or at least no gross reduction) in soil functions and ecosystem services, as well as achieving effective risk management (Cundy et al. 2016). The provision of ecosystem services may compensate some of the limitations of the remediation process. In this context, (aided) phytostabilization should be considered as a management strategy for contaminated sites which offers economic, environmental, and societal benefits (Cundy et al. 2016).

Climatic conditions pose a crucial and obvious limitation to the success of phytomanagement. Temperature controls transpiration, water chemistry, growth and metabolism of plants, and therefore directly affects both contaminant uptake and their fate in plant parts and other ecosystem compartments (Bhargava et al. 2012). Soil moisture affects both plant growth and contaminant transport in soil, and GRO management also needs water management, especially in arid and semi-arid areas that undergo relatively long periods of drought and heatwaves. Prolonged drought induces stress which enhances plants’ sensitivity to pathogens or herbivory and, more importantly, reduces plant growth with negative implications on the phytoremediation success. Additional site-specific problems concern mining areas and sandy soils where soils are often characterized by a low water retention capacity (Kidd et al. 2015).

As mentioned above, a major limitation of phytoextraction is the very long time required to effectively extract metal(loid)s from soils, particularly in medium and highly contaminated sites (Zhao et al. 2003). However, if the aim of the phytoextraction strategy is only to strip the bioavailable metal(loid) fraction from soil ("bioavailable contaminant stripping") and not to reach total metal(loid) concentration targets established by legal frameworks, then the time required for successfully reaching this target is much shorter (Mench et al. 2018; Vangronsveld et al. 2009). Also, for phytoextraction, the low biomass and slow growth of most hyperaccumulators are largely responsible for the long time required. This limitation can be overcome to an extent by using plant species that provide an added value in order to obtain economic benefit during the phytoextraction process itself. Energy crops, such as *Miscanthus* spp., *Ricinus communis* L., *Brassica napus* L., have been proposed due to their metal tolerance and accumulation capacity along with their usefulness for biofuel production (Burges et al. 2018). Other commercial applications of plants used in phytoremediation, such as biochar production, raw materials for industries (oil, paper, bio-chemicals, essential oils, etc.) and medicinal purposes are being studied (Pandey et al. 2016; Schröder et al. 2008). The use of fast growing trees offers the possibility to combine metal (Cd, Zn, Ni) extraction with production of biomass for bioenergy and other end-products (e.g., timber, resin, adhesives, etc.) (Schroder et al. 2008). Recovery of high-value metals or strategic elements, from metal-rich plant biomass is another means of increasing the economic viability of phytoextraction (in this case termed as phytomining), while simultaneously eliminating the need for disposal of the contaminated biomass. Chaney et al. (2007) demonstrated that phytomining of Ni can be highly profitable in Ni-contaminated soils.

Additional aspects that should be considered include the degree of soil contamination, the bioavailability and accessibility of the contaminants, and the capacity of the plants and their associated microorganisms to adsorb, accumulate and/or degrade the contaminants (Vangronsveld et al. 2009). Assisted phytoextraction using chelates has been proposed as a means of increasing metal bioavailability, but an important limitation of chelate-induced phytoextraction is the possibility of promoting metal leaching to other environmental compartments (e.g., groundwater) (Burges et al. 2018).

The establishment and growth of plants on contaminated sites are other major obstacles (Mendez and Maier 2008; Tordoff et al. 2000). In addition to the phytotoxic concentrations of pollutants, contaminated soils usually present edaphic conditions which can severely limit plant growth (nutrient deficiency, poor soil structure, low organic matter, etc.). The careful selection of tolerant and resilient plant species is vital for the long-term success of phytomanagement strategies (Batty 2005; Clemente et al. 2012; Parraga-Aguado et al. 2014). The efficiency of phytotechnologies can also be enhanced by incorporating agronomic practices. For example, plant cropping patterns (rotation, intercropping) can improve plant growth and performance and, depending on the phytotechnology, can be designed so as to enhance or mitigate metal(loid) availability, uptake and accumulation (Kidd et al. 2015). Intercropping, traditionally used in agriculture to increase crop yield, can pair phytoextracting plant species with other crops, in order to promote remediation while providing economic benefits (Burges et al. 2018). The use of deep-rooting plants, mycorrhizal plants or bioinoculants can enhance plant growth and GRO efficiency (Kidd et al. 2009; Kidd et al. 2015). The use of organic and inorganic amendments may optimize plant growth and performance by improving soil physicochemical properties, fertility and microbial activity and diversity (Bolan et al. 2011; Pardo et al. 2014a; Pardo et al. 2014b). In addition, amendments directly or indirectly influence the availability and mobility contaminants through the modification of soil physico-chemical and biological conditions (pH, redox conditions, concentration of chelating and complexing agents, cation exchange capacity, and biological activity) (Kidd et al. 2015; Pardo et al. 2016; Pérez de Mora et al. 2005). Depending on site characteristics a selection of the most appropriate phytomanagement options will be necessary; in some cases the implementation of several approaches may be needed. The combination of different options can be more effective in site remediation than using a single approach.

- **Current status**

Phytomanagement requires the use of appropriate agronomic and crop management practices, and can be assisted through the application of soil amendments. However, long-term field experiments are crucial for monitoring the efficiency and sustainability of phytomanagement options over time. A growing number of studies under field conditions can be found in the literature and these should contribute towards reaching full-scale deployment of these techniques. Such field studies have shown that phytostabilization can effectively reduce trace metal(loid) mobility by altering speciation, as well as to improve soil physicochemical properties and fertility, increase microbial diversity and restore functionality in the long-term (Clemente et al. 2012; Kumpiene et al. 2009; Mench et al. 2018; Pardo et al. 2017; Pardo et al. 2016; Pardo et al. 2014c; Pardo et al. 2014d; Quintela-Sabarís et al. 2017; Xue et al. 2015; Xue et al. 2018; Zornoza et al. 2012). At any given site, it will be necessary to implement a long-term monitoring programme so as to ensure that any reduction achieved in metal toxicity and improvement in soil quality are maintained (Epelde et al. 2014).

Phytoremediation processes are governed by the interactions between three key players: soil, plants and microorganisms, and some biotic interactions. The last few years have seen a growing interest in the influence of microorganisms on plant growth and contaminant bioavailability and degradation. A growing body of results indicate a crucial role of plant-associated microorganisms in improving phytoremediation success ((Afzal et al. 2014; Benizri and Kidd 2018; Deng and Cao 2017; Feng et al. 2017; Kidd et al. 2017; Lenoir et al. 2016; Sessitsch et al. 2013; Thijs et al. 2016). Rhizosphere and endophytic organisms that have received much attention because of their beneficial effects on plant growth health and resistance to stress are the plant growth-promoting bacteria (PGPB), mycorrhizal and endophytic fungi (Coninx et al. 2017; Mendes et al. 2013). Microorganisms can increase the availability of essential plant nutrients, such as nitrogen (N_2-fixing organisms), phosphorus (by solubilization or mineralization through the production of organic acids and/or phosphatases) or iron (by releasing Fe(III)-specific chelating agents or siderophores). Plant growth-promoting bacteria can also directly influence plant growth and physiology through the production of phytohormones (e.g., IAA or by reducing stress ethylene levels in plants through the production of the enzyme 1-aminocyclopropane-1-carboxylate deaminase). Some bacteria can inhibit or reduce plant diseases indirectly by competing for nutrients and space (niche exclusion), producing antimicrobial compounds or through the induction of plant defence mechanisms (Compant et al. 2005; Lemanceau et al. 2007).

Several field-based trials implementing phytostabilization in metal-contaminated soils have shown the benefits of organic-based amendments for recovery of soil biological fertility. Microbial biomass and soil enzymatic activities were higher in acidic mine soils amended with pig manure/sewage sludge/marble waste than in the untreated mine tailings (Zanuzzi et al. 2009; Zornoza et al. 2012). Touceda-González et al. (2017a) amended highly acidic Cu mine tailings with composted municipal sewage wastes and established a SRC system and a grassy cover. Microbial activity was stimulated and led to the establishment of vital biogeochemical cycles. Pardo et al. (2014d) successfully used olive-mill waste compost as a soil amendment to promote the growth of a native legume (*Bituminaria bituminosa* (L.) C. H. Stirt.) in a mine-affected soil from a semi-arid area (Southeast Spain) contaminated with trace elements (As, Cd, Cu, Mn, Pb and Zn).

However, the use of amendments has to be carried out with caution as amendments can have undesirable effects: for instance, an inappropriate use of organic amendments can result in underground water contamination by nitrates, antibiotics, hormones, and loss of soil biodiversity, posing a risk to environmental and human health (Burges et al. 2018; Burges et al. 2016; Goss et al. 2013). Organic and inorganic amendments can induce other negative effects like destruction of soil structure, addition of potentially toxic compounds, immobilization of essential nutrients, etc. (Alkorta et al. 2010). Moreover, although amendments have demonstrated to aid revegetation, plant roots may not extend readily from a fertile layer into underlying non-amended contaminated soil (Pulford and Watson 2003), limiting the potential of this phytotechnology to the top layer of soil.

- **Legal and regulatory framework**

Key concerns regarding the increasing loss of soil quality through degradation or contamination of soils led the European Commission to develop a Soil Framework Directive (EC, 2006) which presented a Thematic Strategy toward soil protection considering eight main threats to European soils: (1) erosion, (2) loss of organic matter, (3) contamination, (4) compaction and other physical soil degradation, (5) salinization, (6) decline of biodiversity, (7) soil sealing by infrastructure, and (8) floods and landslides (EC, 2006). Unfortunately, this Thematic Strategy was not accepted by all EU Member Countries. The Global Soil Partnership (GSP) was established in 2012 by the Food and Agriculture Organization of the United Nations (FAO) in order to develop interaction and enhanced collaboration amongst all relevant stakeholders (from land users to policy makers) towards the development of soil legislation and sustainable soil management measures. This proposal was very important and promoted a discussion on how to translate soil science into environmental policies (Bouma et al. 2017). The Intergovernmental Technical Panel on Soils (ITPS), which was established at the first Plenary Assembly of the GSP in 2013, published the first-ever comprehensive report on the State of the World's Soil Resources (SWSR) (FAO and ITPS, 2015). Major threats to soil functions at a global scale were identified as soil erosion, loss of soil organic carbon, nutrient imbalance, and salinization and sodification. Requirements for soil protection are also often included in other EU policies, such as the Nitrates Directive and the Water Framework Directive, and in the national legislations of various European countries, specifically addressing water, waste, and mining regulations. Although these policies consider soil contamination and contribute indirectly to soil protection, they only feature soil as a secondary objective.

The legislation available in many industrialized countries, regulating local soil contamination, and guidelines for assessing potentially contaminated soils, is based on total contaminant concentrations. However, negative effects of metal(loid)s on soil functioning is known to be related to mobile/bioavailable elemental pools rather than total metal concentrations (Kumpiene et al. 2009). Therefore the site-specific approach based on conceptual model, pollutant linkages and risk assessment is more and more adopted in European countries (e.g. France, UK, Germany, etc.). On the other hand, it is often the case that bioavailable concentrations show no correlation with total concentrations (Burges et al. 2015). There is a general consensus that metal(loid) bioavailability is more important for environmental protection and risk assessment than total metal(loid) concentrations because it represents the labile fraction subject to leaching and uptake by soil organisms (Madejón et al. 2006). In recent years, more sophisticated risk-based approaches to deal with the local effects of soil pollution have been developed, which include the concept of pollutant linkages (contaminant-receptor-pathway). Decision makers and regulatory organizations have accepted that bioavailability of soil contaminants is a key variable to be taken into consideration in risk assessment, regulation policies and soil remediation (Naidu et al. 2015). These risk orientated policies focus on the abandonment of policies aimed at restoring soils to their original ‘clean’ state. Some national trigger values classifying soils as contaminated or requiring remediation now have bioavailability explicitly (e.g., in the UK, Belgium, Switzerland) or implicitly (trigger values set according to the main influencing soil physicochemical properties, e.g., soil pH, granulometry, organic matter content) embedded within them. Several phytomanagement options are aimed at removing the bioavailable contaminant fraction (“bioavailable stripping”), a target which significantly reduces the length of time required for rehabilitation.

There is now an emerging consensus in the broad frameworks and approaches for sustainable remediation being developed around the world (Bardos 2014) which is culminating in the drafting of international standards by ISO and ASTM International. The fundamental basis of sustainable remediation is to promote the use of more sustainable practices during environmental clean-up activities, with the objective of balancing economic viability, conservation of natural resources and biodiversity, and the enhancement of the quality of life in surrounding communities. In broad terms, concepts of sustainable remediation are based on achieving a net benefit overall across a range of environmental, economic, and social concerns that are judged to be representative of sustainability. This is a key goal in land remediation and land regeneration, given the large global contaminated land legacy and the overall resource and financial cost required to bring this land back into beneficial use. The implementation of the International Organization for Standardization (ISO) Standard on Sustainable Remediation is now at an advanced stage (Bardos et al. 2016). Remediation begins with an option appraisal that short lists strategies that could deliver the required reduction in risk. A remediation strategy comprises one or more remediation technologies that will deliver the safe and timely elimination and/or control of unacceptable risks. The ISO standard will help assessors identify the most sustainable among the shortlisted, valid alternative remediation strategies.

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Who should use this guidance

You should use this guidance as an introduction to how to:

- use risk assessments to consider dangers soil contamination, by either metal(loid)s or mixed contaminants, might cause;

- find relevant solutions to (phyto)manage soil contamination, accounting for conceptual model, money and time available;

- (phyto)manage soil contamination by developing and implementing a plan based on the results of risk assessments and appraisal of feasible options;

- check the beneficial effects and limits of (phyto)management regarding soil ecological processes and functions underlying ecosystem services;

- assess that (phyto)management of soil contamination is efficient, done properly and legally.

You should use this guidance if you are:

- redeveloping/reusing contaminated/degraded land;

- managing soil contamination on your land voluntarily;

- managing soil contamination because you have to by law;

- making decisions on the (potential) (phyto)management of soil contamination on site(s) on behalf of someone else;

- being a stakeholder associated/involved in the (phyto)management of land with a metal(loid)-contaminated soil.

Caution: You will need help from experts and/or specialist consultants and academics who are suitably qualified and competent. Most success stories associated academics, local/national authorities/ stakeholders, and qualified consultants/ companies, with relevant knowledge and experience.

Introduction

This guidance promotes a refocus from phytoremediation to wider GROs- or phyto-management based solutions which place realization of wider benefits at the core of site design, and where GROs can be applied as part of integrated, mixed, site risk management solutions or as part of “holding strategies” for vacant sites.

The combination of GROs with renewables, both in terms of biomass generation and green technologies (e.g. wind and solar power), can provide a range of economic and other benefits.

This can potentially support the return of low-level risk sites to productive usage. Combining GROs with either urban or rural design and landscape architecture, and integrating GROs with sustainable urban drainage systems, small catchment (eventually related to constructed wetlands) and community gardens/parkland (e.g. for health and leisure benefits), has potential for triggering GRO application and in realizing wider benefits in either urban and suburban systems or rural areas. Quantifying these wider benefits and value are important in leveraging funding for GRO application and soft site end-use more widely at vacant or underutilized sites.

Risk management solutions request:

1) a clear and unambiguous definition of contaminated land,

2) a decision making process that follows a risk based approach,

3) a compliance with a regulatory system that is consistent, transparent, and integrative,

4) implementation of funding mechanisms, education and training of professionals and program to create public awareness and gain public support.

Context - Contaminated land

One step is to have a statuary definition of contaminated land, which allows to differentiate between lands that are considered contaminated land and those that are not, for establishing the extent and scale of contamination.

- in many European countries, e.g. France, it is a risk-based management approach, with comparison of the metal(loid) and xenobiotic concentrations in the soils with their background levels in similar soil types in the surrounding, and according to land use (and regulations on air, water, green fodders, etc. when soils are secondary sources of exposure towards environmental and biological receptors);

France

● Legislation for managing contaminated sites and soils in France is available at:

To manage sites on the French priority list: Risk prevention and actions against pollution

Web site of Environment Ministry, Classified Installations Inspections:

- http://www.installationsclassees.developpement-durable.gouv.fr/-Site-national-PPRT-.html

http://www.installationsclassees.developpement-durable.gouv.fr/-Sites-et-sols-pollues-.html

French guidelines for managing polluted sites and soils (in force since 2007 and revised in April 2017)

https://www.ecologique-solidaire.gouv.fr/sites-et-sols-pollues#e1

http://circulaire.legifrance.gouv.fr/pdf/2017/04/cir_42093.pdf http://ssp-infoterre.brgm.fr/methodologie-nationale-gestion-sites-sols-pollues

http://ssp-infoterre.brgm.fr/page/politique-gestion-sites-sols-pollues

feedback on the French directive in force since 2017: http://www.installationsclassees.developpement-durable.gouv.fr/IMG/pdf/2_JTSSP_2017_MethodoSSP_BSSS_C_Vincq.pdf

Database on industrial sites recorded on the French priority list:

- http://www.installationsclassees.developpement-durable.gouv.fr/rechercheICForm.php

● Methodological guides to implement feasible management options on a polluted site.

http://www.installationsclassees.developpement-durable.gouv.fr/Outils-de-gestion.html#tex

http://www.installationsclassees.developpement-durable.gouv.fr/Outils-de-gestion.html#guidesis

http://ssp-infoterre.brgm.fr/methodes-et-outils

all documents and files can be downloaded from these pages

Including:

- "Ministry tools" (**management tools**), designed to specify the methods for implementing management options. These are instructions for use specifying the scope and application limits of each step.

- '**Supporting documents**', designed by third parties (ADEME, BRGM, INERIS ...) at the request of the Ministry to support the management process.

List of management tools:

- Visit of the site
- Site assessment
- Conceptual and operating models
- The interpretation of the state of environments - Description – Grid of calculation
- Development of Cost-Benefit Assessments adapted to the management contexts of polluted sites and soils
- Residual risk assessment
- Control and management of pollutant impacts on groundwater quality
- Groundwater quality monitoring applied to ICPEs and polluted sites
- Ordering Guide
- Guide for implementing the restrictions of use applicable to polluted sites and soils
- Guide for court administrators, court agents and classified facilities inspectors
- Guide to constructive measures for use in the field of polluted sites and soils
- Guide for off-site reclamation of excavated soil from sites and potentially polluted soils in development projects

http://www.upds.org/images/stories/gt_terres_excavees/2017-11-Guide_Valorisation_TEX_SSP.pdf

- Nature of petroleum products and aging origin: attempt to identify the source accounting for impacts and analyzing the approximate age of spills

Management of sites potentially polluted by radioactive substances

List of supporting documents

- Generic criteria for soil quality and management of site-specific management: issues, advantages and disadvantages in the French context

Characterization of the state of soils, waters and plants in the environment of industrial installations - Use of the local reference environment

Measures and Models: issues, advantages and disadvantages in the context of managing polluted sites

Existing databases on soil quality: content and use in the management of polluted soils

Summary of regulatory values for chemical substances, in force for water, foodstuffs and the air in France on December 31, 2017

Origin and method of elaboration for the regulatory values related to water, air and foodstuffs, in force in France for chemical substances

Development of soil information sectors (SIS) under the ALUR law - Methodological guide for DREAL and stakeholders

Methodological guide for communities related to the soil information sectors (SIS) and the map of old industrial sites and service activities (CASIAS)

What techniques for which treatments - Cost-benefit analysis

Define a clean-up strategy: Approach based on the pollutant mass and the release capacity of a pollution

Characterization of Indoor air quality in relation to potential soil pollution by volatile and semi-volatile chemicals

Practical guide for characterizing gazes in soils and indoor atmosphere in line with soil and / or groundwater pollution

● Datasets for background levels in French soils are available at:

Baize D Informations sur les éléments traces dans les sols en France (*information on trace elements in French soils and plant parts*) http://www.denis-baize.fr/etm/webetmbi.html

Baize D 1997. Teneurs totales en éléments traces métalliques dans les sols (France). Editions Quae

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Base de données Eléments traces métalliques BDETM INRA orléans http://www.gissol.fr/le-gis/programmes/base-de-donnees-elements-traces-metalliques-bdetm-65

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Ademe- BRGM: BDSolU. Database for French urban soils. http://www.bdsolu.fr/page/objectifs

● Background levels in French plant parts

Meta(loid)s

ADEME INERIS, CNAM, INP, ENSAT, ISA, INRA 2012 Base de données des teneurs en éléments traces métalliques de plantes potagères (BAPPET) : présentation et notice d'utilisation (Database for trace elements in kitchen vegetables (BAPPET): presentation and instructions for use) https://www.ademe.fr/base-donnees-teneurs-elements-traces-metalliques-plantes-potageres-bappet-presentation-notice-dutilisation

ADEME 2015 Success stories R&D : BAPPET, une base de données sur la contamination des plantes potagères par des éléments traces métalliques https://www.ademe.fr/success-stories-rd-bappet-base-donnees-contamination-plantes-potageres-elements-traces-metalliques

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- in other countries, e.g. Spain, the national legislation is considering maximum permitted concentrations for total soil metal(loid)s, generally with threshold values accounting for residential, industrial and agricultural activities.

● Legislation for managing contaminated sites and soils in Spain is available at:

Ley 22/2011, de 28 de julio, de residuos y suelos contaminados

https://www.boe.es/buscar/act.php?id=BOE-A-2011-13046

For the Basque Country

LEY 4/2015, de 25 de junio, para la prevención y corrección de la contaminación del suelo.

http://www.euskadi.eus/bopv2/datos/2015/07/1502935a.pdf

● Datasets for background levels in Spanish soils are available at:

Guía Técnica de aplicación del RD 9/2005, de 14 de enero, por el que se establece la relación de actividades potencialmente contaminantes del suelo y los criterios y estándares para la declaración de suelos contaminados

For the Basque Country

Volumen 8. Valores indicativos de evaluación (VIE-A, VIE-B, VIE-C) (1,88 Mb)

● Background levels in Spanish plant parts

Not available

● Legislation for managing contaminated sites and soils in Portugal is available at:

No specific guidance for site assessment and remediation is formally available in Portugal. In the absence of a national contaminated land management strategy, the prevention and detection of soil contamination problems has been deal within the scope of the national waste management strategy; soil contamination and remediation are included in environmental and waste management regulations.

Provisions regarding soil protection and soil decontamination are found in several legislative instruments:

- Decree-Law nº 89/2002 - Strategic Plan for the Management of Industrial Waste

https://dre.pt/pesquisa/-/search/302769/details/maximized

- Decree-Law nº 118/2006 – Regulates the use of sewage sludge in agriculture to prevent harmful effects on soil, plants and humans

https://dre.pt/pesquisa/-/search/371037/details/maximized?print_preview=print-preview
amended in 2009 by the Decree-Law nº 276/2009

https://dre.pt/pesquisa/-/search/490974/details/maximized

- The Portuguese Environmental Framework Law – Law nº 11/87 amended by Law nº 19/2014

https://dre.pt/pesquisa/-/search/25344037/details/maximized

- Decree-Law nº 516/99 - defines the Portuguese Strategic Plan on Industrial Wastes

https://dre.pt/web/guest/pesquisa/-/search/626842/details/maximized

- Decree-Law nº178/2006 – sets the legal framework for decontamination of contaminates sites and assigns the responsibility for licensing decontamination projects to regional authorities of waste management

https://dre.pt/web/guest/pesquisa/-/search/540016/details/normal?p_p_auth=1Wtbyzuu

amended by the Decree-Law Nº 71/2016 - waste management regime and lays down certain principles and rules in particular at treatment of contaminated soil

http://data.dre.pt/eli/dec-lei/71/2016/11/04/p/dre/pt/html

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Italy:

● Legislation for managing contaminated sites and soils in Italy is available at:

http://www.isprambiente.gov.it/it/temi/suolo-e-territorio/siti-contaminati

● Datasets for background levels in Italian soils are available at:

Regional data available. Example for Region Emilia Romagna:

https://webbook.arpae.it/indicatore/Contenuto-di-metalli-nel-suolo-00001/?id=ef258eb9-6369-11e5-bf2c-11c9866a0f33

http://ambiente.regione.emilia-romagna.it/geologia/temi/metalli-pesanti/biodisponibilita-metalli-pesanti-nel-suolo

● Background levels in Italian plant parts

No general website or data base available

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● Legislation for managing contaminated sites and soils in Poland is available at:
ROZPORZĄDZENIE MINISTRA ŚRODOWISKA z dnia 1 września 2016 r.
w sprawie sposobu prowadzenia oceny zanieczyszczenia powierzchni ziemi
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● Background levels of plant parts in Poland

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Pająk M., Halecki W., Gąsiorek M. 2017. Accumulative response of Scots pine (Pinus sylvestris L.) and silver birch (Betula pendula Roth) to heavy metals enhanced by Pb-Zn ore mining and processing plants: Explicitly spatial considerations of ordinary kriging based on a GIS approach. Chemosphere. 168: 851-859

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https://link.springer.com/article/10.1007/s12011-016-0645-z

Norway:

● Legislation for managing contaminated sites and soils in Norway is available at:

- A guide "Health based status classes with respect to soil contamination in Norway"; http://www.miljodirektoratet.no/old/klif/publikasjoner/2553/ta2553.pdf
- A data base of contaminated sites in Norway and Svalbard can be found on: http://www.miljostatus.no/tema/kjemikalier/forurenset-grunn/
- Contaminated areas: Miljødirektoratet: Forurenset grunn; http://www.miljodirektoratet.no/no/Tema/Forurenset_grunn/
- Grounds with contaminated soils. Miljødirektoratet: Eiendommer med forurenset grunn: https://grunnforurensning.miljodirektoratet.no/
- Action plan for cleaning contaminated soils in kindergarten and on play grounds: Handlingsplan for opprydning i forurenset jord i barnehager og på lekeplasser
- https://www.regjeringen.no/globalassets/upload/kilde/md/prm/2006/0221/ddd/pdfv/299388-handlingsplan_for_opprydning_i_barnehager.pdf
- Network: Miljøringen. Nettverk for forurenset grunn og sedimenter http://miljoringen.no/

- Government`s plans and legislation: Working together towards a non-toxic environment and a safer future – Norway's chemicals policy; **St.meld. nr. 14 (2006-2007) Sammen for et giftfritt miljø:**

https://www.regjeringen.no/no/dokumenter/Stmeld-nr-14-2006-2007-/id441267/

- Forurensningsforskriften kap. 2 om opprydding i forurenset grunn ved bygge- og gravearbeider: Legislation related to cleaning of contaminated soils at building and digging sites.
https://lovdata.no/dokument/SF/forskrift/2004-06-01-931/KAPITTEL_1-2#KAPITTEL_1-2

Former industrial and other anthropogenic activities have impacted large areas of land around the world. These include urban brownfield sites, former mining, smelting and resource extraction sites, and urban and rural areas affected by diffuse contamination.

At least one million potential brownfield sites would occur across the European Union (Oliver et al., 2005). A considerable fraction of which may have real or perceived contamination problems (Panagos et al., 2013). In the European Union, approximately 10 million ha are contaminated by metal(loid)s from either anthropogenic or geochemical sources (Evangelou et al., 2012) totaling 1.5 million, and potentially up to 3 million of anthropogenic contaminated sites (Mench et al., 2010; Panagos et al., 2013). The US EPA tracks nearly 9 million ha of possibly contaminated land (UEP Agency, 2013).

The German register of contaminated sites lists about 300,000 potentially contaminated sites (UBA, 2015). In France, 264 758 sites are recorded in the national inventory of past and present industrial sites and service activities with a potential pollutant source (BASIAS, 2015). The French Basol database references 6319 polluted sites requiring government action, mainly located in Rhone-Alpes (17%), Nord-Pas-de-Calais (10.5%), Aquitaine (9%) and Ile de France (8.6%) (Commissariat Général au Développement Durable, 2013; Basol, 2016). In France, Pb, Cu, Cd and Zn are respectively involved in 24, 20, 11 and 4.3 % of sites with a metal(loid)-contamination of soils and/or groundwater (Basol, 2015). Although the extent of diffuse contamination is less well-known thousands of square kilometers of land are potentially affected (Bardos et al., 2011). In Belgium and the Netherlands, which share a similar history of industrial development and subsequent partial industrial decline, diffuse contamination by metal(loid)s affects approximately 700 km^2 of land (Witters et al., 2009).

- Information for contaminated sites in France are available at:

http://www.installationsclassees.developpement-durable.gouv.fr/Outils-de-gestion.html#tex

Basol: Database on (potentially) polluted soils and sites requiring a governmental action, to prevent or to remediate. https://basol.developpement-durable.gouv.fr/recherche.php

Basias: national inventory of past and present of industrial sites and service activities. http://www.georisques.gouv.fr/dossiers/inventaire-historique-des-sites-industriels-et-activites-de-service-basias#/

New system managed by the BRGM and Georisques portal

http://www.georisques.gouv.fr/breves/les-secteurs-dinformations-des-sols-sis

http://www.georisques.gouv.fr/dossiers/sis-secteur-dinformation-sur-les-sols/donnees#/

Trade unions of companies working of remediation of polluted soils

http://www.upds.org/

French Environment Agency

https://www.ademe.fr/expertises/sols-pollues/passer-a-laction/depollution-sols

- Information for contaminated sites in Spain are available at:

Polluted soil inventories are regional community's responsibility.

For the Basque Country there is an "Inventario de suelos que soportan o han soportado actividades o instalaciones potencialmente contaminantes del suelo".

http://www.geo.euskadi.eus/s69-bisorea/es/x72aGeoeuskadiWAR/index.jsp?lang=ES&xmin=-448147.90882976&xmax=-154631.72021468&ymin=5227412.8003545&ymax=5382730.8418299&closestZoom=true&srsbox=EPSG:3857&base_layer=Ortofoto-cartografia&layers=medio_ambiente-suelos_contaminados

ftp://ftp.geo.euskadi.eus/cartografia/Medio_Ambiente/Suelos_Contaminados

● Information for contaminated sites in Portugal are available at:

The Portuguese Environmental Agency published a report about the environmental liabilities in Portugal undertaken as part as the National Plan for Environment and Health Action https://poseur.portugal2020.pt/media/38027/01_doceng_passivoambiental.pdf.

Priority areas of intervention, according to the report are:

1) soils from the Chemical Complex of Estarreja, a mercury–cell chlor-alkali plant (mainly Hg, As, Pb and Zn);
2) soils from the National Steel Industry in Seixal (Cr, Cu, Ni, Pb, Zn, Hg and As);
3) soils from the former industrial zone of Barreiro - **Organic Chemical Industry** - refining of oils, soaps, flours and rations; **Inorganic Chemical Industry** - acid manufacture; chemical and Metallurgical Industry of Cu, Pb, Au and Ag as well as the treatment of pyritic ash;
4) iron, bronze and special steel manufacture for the sulfuric acid industry; 12 sludge dams located in adjacent soils of the Sines Petrochemical Complex; Alviela basin (region where about 85% of the country's tanneries is concentrated) and several abandoned metallic and uranium mines and abandoned quarries.

- **Database on polluted Portuguese sites (at least 15409 sites) is available in:**

EPER – European Pollutant Emission Register site from the European Environment Agency in the following report:

The European Pollutant Release and Transfer Register (E-PRTR), Member States reporting under Article 7 of Regulation (EC) No 166/2006

https://www.eea.europa.eu/data-and-maps/data/member-states-reporting-art-7-under-the-european-pollutant-release-and-transfer-register-e-prtr-regulation-21

- **Mines**

https://www.researchgate.net/publication/283994822_Diagnostico_Ambiental_das_Principais_Areas_Mineiras_Degradadas_do_Pais

https://edm.pt/area-ambiental/inventariacao-de-areas-mineiras/

https://www.eea.europa.eu/themes/industry/industrial-pollution/industrial-pollution-country-profiles-2017/portugal-industrial-pollution-profile-2017

- **Information on metal concentrations in soils in Europe (including Portugal)**

http://weppi.gtk.fi/publ/foregsatlas/index.php

Ballabio C, Panagos P, Lugato E, Huang J-H, Orgiazzi A, Jones A, Fernández-Ugalde O, Borrelli P, Montanarella L 2018. Copper distribution in European topsoils: An assessment based on LUCAS soil survey. Science of the Total Environment, 636, 282–298.

Italy

● Information for contaminated sites in Italy are available at

- the website of the MATTM (Ministero dell'Ambiente e della Tutela del Territorio e del Mare): http://www.bonifiche.minambiente.it/ and

- the website of ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale): http://www.isprambiente.gov.it/it/temi/suolo-e-territorio/siti-contaminati.

The list of "Sites of National Interest" is available at http://www.isprambiente.gov.it/it/temi/suolo-e-territorio/siti-contaminati/siti-di-interesse-nazionale-sin. From here it is possible to download a document listing the locations and surface of the sites, and the regulations concerned. The latest list contains about 40 sites. A complete archive of documents is kept in the website: http://www.bonifiche.minambiente.it/

There is an archive with all the contaminated sites subjected to remediation and recovery based on information from Regions and Provinces under construction since 2006 http://www.isprambiente.gov.it/it/temi/suolo-e-territorio/siti-contaminati/anagrafe-dei-siti-da-bonificare

and

Falconi M, Perez A P, D'Aprile L, Vecchio A 2017 Management of contaminated sites in Italy and Europe. Intersol 2017 https://www.intersol.fr/edition2017.php

16619 ha over 14 regions; from 16% to 0% of these Italian registered contaminated sites are remediated depending of the Italian regions

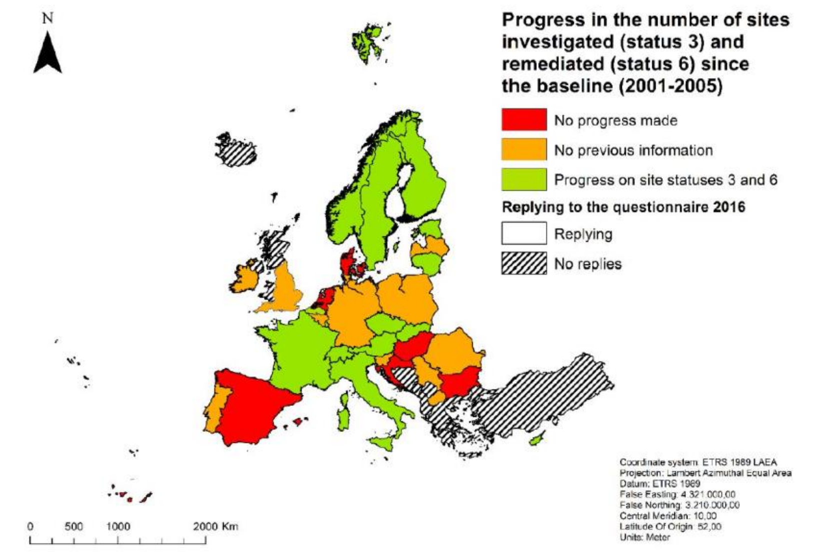
Norway

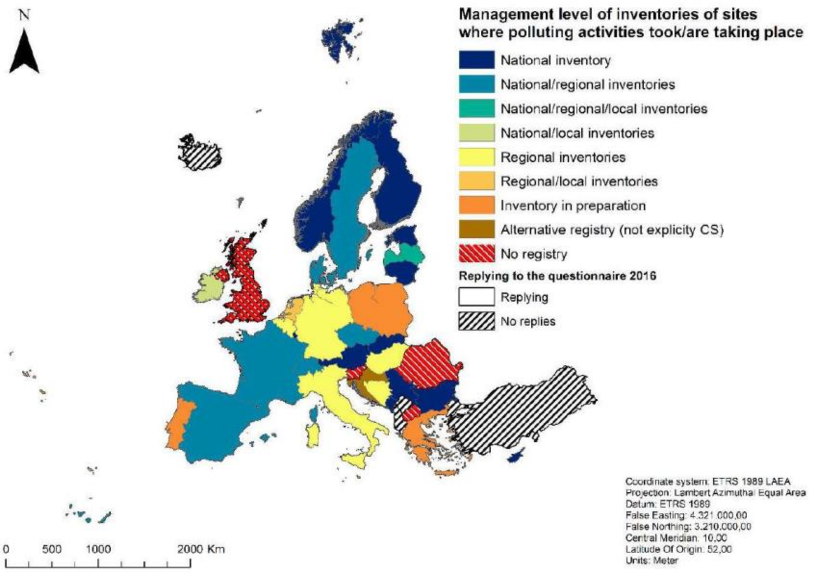
- A data base of contaminated sites in Norway and Svalbard can be found on: http://www.miljostatus.no/tema/kjemikalier/forurenset-grunn/
- Contaminated areas: Miljødirektoratet: Forurenset grunn; http://www.miljodirektoratet.no/no/Tema/Forurenset_grunn/
- Grounds with contaminated soils. Miljødirektoratet: Eiendommer med forurenset grunn: https://grunnforurensning.miljodirektoratet.no/

Europe

According to a Joint Research Centre (JRC, European Commission's science and knowledge service) report in 2018, countries across Europe are making progress on tackling soil contamination (Pérez and Rodríguez Eugenio, 2018). Of the 39 countries surveyed, 28 maintain inventories for contaminated sites at different administrative levels - national, regional or local. The management of contaminated sites in Europe has improved substantially. The survey included 39 countries, of which 25 are EU Member States. Within the EU there are an estimated 2.8 million sites where artificial surface indicates that polluting activities have occurred in the past. According to national and regional inventories of countries, more than 650,000 sites are registered where polluting activities took or are taking place. The number of remediated sites or sites under aftercare measures has increased from 57,000 to 65,500 in the last five years. Over 5,000 new sites are under remediation or risk-reduction measures and more than 76 000 new sites have been registered since 2011 Investigations of more than 170,000 sites are still pending. 125 000 sites need or might need remediation. An average of 3.6 contaminated sites per square km of artificial surface are registered in the country inventories of EU Member States. Poland and Portugal are preparing their inventory, which will be managed at regional and at national level, respectively.

Since 2011, Cyprus has developed its national register of contaminated sites and Malta is currently collecting information on contaminated sites.





Pérez A P, Rodríguez Eugenio N 2018 Status of local soil contamination in Europe: Revision of the indicator "Progress in the management Contaminated Sites in Europe, EUR 29124 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-80072-6, doi:10.2760/093804, JRC107508. https://ec.europa.eu/jrc/en/news/countries-across-europe-make-progress-tackling-soil-contamination.

1843 sites in Colombia are considered potentially contaminated, main contributors of brownfields being the mining sector (42%), notably Hg use for gold mining, the oil and gas sector (24%, roughly 6000 ha of land for potential agricultural use) and the waste management sector (14%) (Arias-Espagna et al. 2018)

Data for China, Russia

The term **pollutant linkage** refers to the combination of a **source-pathway-receptor**, as reported in the Greenland guideline (http://www.greenland-project.eu) while the term exposome encompasses the totality of human environmental (i.e. non-genetic) exposures from conception onwards, complementing the genome (Wild, 2005). The reduction of pollutant linkages is of major concern in this context (Defra, 2012; Cundy et al., 2013).

A number of impacted sites have been remediated or restored to productive use. However a significant land area remains derelict or underutilized because its restoration is uneconomic or unsustainable using conventional methods. This is found for large land areas where contamination may be causing concern but is not present at highly elevated levels (e.g. areas impacted by diffuse metal(loid) smelter contamination), or where smaller sites are economically marginal for hard redevelopment (e.g. where economic returns from site redevelopment for housing are insufficient to cover conventional remediation costs).

Since the 1990s, an expanding body of work claims that management and reutilization of these sites is possible through use of low input longer term remediation options (e.g. ITRC, 2009), including so-called gentle remediation options (GROs) (Mench et al., 2010; Kidd et al., 2015).

Marginal land

FAO reported the world has 610 million ha of unforested marginal land. Tilman et al (2006) claimed at least 500 million ha, but this includes land areas where tropical forests were destroyed for plantations and cattle ranching and where soil degradation and water depletion now make agriculture difficult. Field et al (2008) suggest that 386 million ha of abandoned cropland useable for bioenergy exist. Several governments have taken steps to identify idle, underutilized, marginal or abandoned land and to allocate it for commercial biofuel production. In Indonesia, approximately 27 million ha of “unproductive forest lands” could be offered to investors and converted into plantations. Exact figures on marginal lands are not available at a European scale. The figures range from 11% in the UK to 82% in Spain. In the EU the 10% of cropland that had been set aside since the 1990s is rapidly being turned into intensive monocultures, also following lobbying by the agrofuel industry and high commodity prices. Since set asides were scrapped in autumn 2007, 1.5 million ha have been put under the plough.

In the Basque Country there are approximately 7.900 ha of potentially polluted soil (Gipuzkoa 32.5%, Vizcaya 44%, Álava, 13.5%) representing 16.5% of the Basque Country urban land.

Risk-based management

Risk based-management vs. total clean-up of contaminated sites

● Assessing risks due to soil contamination means you can estimate the pollutant linkages, what is happening/might happen as deleterious effects and how bad it would be, and use this knowledge to help make decisions. Uncertainties must be reduced where you can and explained if they remain.

● It may be difficult to get accurate and exhaustive dataset for type, concentration and chemical speciation of soil contaminants, their spatial variability and predict what harm soil contaminant may cause for reasons including:

- a lack of scientific information about behavior of substances (e.g. metal(loid)s) or xenobiotics in the soil)
- spatial variability of contaminant levels in the soil layers
- the impacts/pollutant linkages due to soil contaminants depend on land use, soil type, climatic conditions, and other circumstances
- the uncertainties to predict when and how substances might cause harm to people and/or animals and microbes, environmental compartments (e.g. fresh water, groundwater, etc.), or might react with other substances in the soil to cause these effects, because every person and situation is different.

(Environment Agency, 2010)

In most cases, it is recommended to carry a risk-based management rather than relying on total soil contaminants.

<u>Carry out risk assessments</u>

You must start with a preliminary risk assessment to:

- define the objectives of the assessment
- collect basic information about the site and any contamination risks
- decide if any further assessments are needed

You may then have to use one or both of the following risk assessments to estimate how serious soil contamination is.

- a generic quantitative risk assessment - to collect more site information for comparison with general standards, also known as generic assessment criteria (GAC), to decide if the level of risk needs more detailed assessment or a plan for dealing with the contamination;

- a detailed quantitative risk assessment - to collect more site information for comparison with bespoke standards, also known as site specific assessment criteria (SSAC), so you can decide if you need to create a plan to deal with any contamination

Risk assessments get increasingly complex, involve more data and are likely to take more time as you move from preliminary to generic to detailed risk assessments. Each stage builds on the information discovered in the previous stage.

Risk based land management has the fundamental principle of ensuring that land and water is fit for purpose (i.e. appropriate for future use) and does not pose an unacceptable risk to human health or the environment. <u>It establishes that there has to be exposure before harm from the exposure can occur.</u> This maxim distinguishes between harm and risk and that means that without receptors being exposed to site contamination, the chance of exposure is zero and harm cannot occur and consequently the risk cannot be realized.

Added benefits of the risk based land management are that it can be incorporated into “environmental regulation” to avoid remediation strategies that are prescriptive and avoids unnecessary assessments and the associated costs; it allow solutions that are suitable for future land use, i.e. fit for purpose (Reinikainen and Sorvari, 2016).

PhytoSUDOE aims

GT1 is contributing to establishing a network of phytomanaged contaminated/degraded sites within the SUDOE region to evidence the efficiency of phytotechnologies for ecologically remediating soils and enhancing soil services. GT1 is considering 3 objectives at all sites:
(1) risk assessment
(2) option appraisal
(3) remediation strategy: operation plan; final data aggregation and verification; benefits from crops and soil services

A main set of 8 contaminated sites (n=2 for Portugal, Galicia, Basque Country and France) and 3 additional sites were characterized for implementing and evaluating phytomanagement options (energy and woody crops, perennial grasses and high yield crops for ecomaterials and biosourced chemistry, hyperaccumulators for ecocatalysis and phytomining, biochars & composts) to improve ecological functions associated to soil services, alleviate pollutant linkages/risks, produce useable biomass for the Bioeconomy and any other ecosystem services.
Deliverables are: initial soil properties, exposures to metal(loid)s and organics via soil-to-root pathway, dermal contact and soil ingestion, soil toxicity, contaminant phytoavailability and bioaccessibility, feasible phytomanagement options, potential use and financial returns from biomass, potential changes in risk levels and pollutant linkages, overall verification of targeted objectives.

In a risk-based management a link between the source (pollutant) and the receptor(s) must be established (i.e. adopt the source-pathway-receptor (SPR) model) (Reinikainen and Sorvari, 2016). If there is no link there is no risk, but if risk exists, an assessment is required to identify those sites that potentially present a risk to receptors (Nathanail et al., 2013).

One of the issues of risk-based land management is the perception of perpetual management of the hazard (source) if the chemical substances are not removed. Consequently, questions of ongoing liability and transfer of information remain. When there is a strong emphasis on hazards in a setting of public outrage, a risk based management may not gain the support of several stakeholders. This requires from the start of the risk assessment to educate stakeholders, to allow communities to become contributors to scientific knowledge and at the same time maintain their sense of natural justice and exchange of ideas via forums related to remediation (e.g. CleanUp Conference Series by CRC for Contamination Assessment and Remediation of the Environment (CARE) in Australia, Sustainable Remediation Forum for Australia & NZ (SuRF ANZ), Sustainable Remediation Forum for UK (SuRF UK) and collaboration with Environmental authorities, e.g. EPAs.

Soil monitoring

- UK:

https://www.gov.uk/government/collections/monitoring-emissions-to-air-land-and-water-mcerts#soil-monitoring

- FR:

● Caractérisation de l'état des milieux sols, eaux et végétaux dans l'environnement des installations industrielles - Utilisation de l'Environnement Local Témoin ;

https://www.ineris.fr/fr/caracterisation-de-letat-des-milieux-sols-eaux-et-vegetaux-dans-lenvironnement-des-installations

● Bases de données existantes relatives à la qualité des sols : contenu et utilisation dans le cadre de la gestion des sols pollués

http://www.installationsclassees.developpement-durable.gouv.fr/Outils-de-gestion.html#elt

- SP

●Inventario de suelos que soportan o han soportado actividades o instalaciones potencialmente contaminantes del suelo (Basque Country)

ftp://ftp.geo.euskadi.eus/cartografia/Medio_Ambiente/Suelos_Contaminados/

●Mapa del grado de erosión hídrica de los suelos

http://www.euskadi.eus/contenidos/documentacion/mapa_erosion/es_erosion/adjuntos/memoria.pdf

- PT

Recolha de Informação Nacional sobre solos e sedimentos contaminados. Volume I Compêndio de questionários. Plano Nacional de Acção Ambiente e Saúde. EP Solo e Sedimentos - Agência Portuguesa do Ambiente. https://www.apambiente.pt/_cms/view/page_doc.php?id=447

Databases

- link to Portuguese Environmental Atlas: https://sniamb.apambiente.pt/
- geoPortal do LNEG – Geoscientific information of occurrences of Portuguese Mineral Resources http://geoportal.lneg.pt/index.php?option=com_wrapper&view=wrapper&Itemid=55&lg=pt

Ferreira A, Batista MJ, Martins L, Pinto MS 2003. Regional and FOREGS Geochemical Baseline Surveys of Portugal – A Comparison.

https://www.researchgate.net/publication/262409945_Regional_and_FOREGS_Geochemical_Baseline_Surveys_of_Portugal_-_A_Comparison

Inácio M, Pereira VG, Pinto MA 2008. The Soil Geochemical Atlas of Portugal: Overview and applications. Journal of Geochemical Exploration, 98, 22-33 DOI: 10.1016/j.gexplo.2007.10.004

Inácio M, Pereira VG 2015. Geochemical Atlas of Continental Portugal: Macro and micronutrients their distribution and availability. In: O Solo na Investigação científica em Portugal, Publisher: ISAPress, Lisboa, MM, Fangueiro D, Santos E (Eds). pp.73-77

https://www.researchgate.net/publication/318348642_Geochemical_Atlas_of_Continental_Portugal_Macro_and_micronutrients_their_distribution_and_availability

Nunes JR, Ramos-Miras JA, Lopez-Piñeiro L, Loures CG, Coelho J, Peña D 2014. Geochemical Baseline Concentrations of Available Heavy Metals in Mediterranean Agricultural Soils: A Case Study in calcareous soils of Southwest Iberian Peninsula. Advances in Environmental Sciences, Development and Chemistry. ISBN: 978-1-61804-239-2 http://www.inase.org/library/2014/santorini/bypaper/ENVIR/ENVIR-36.pdf

Risk assessment report

● *At each stage of risk assessment you should produce a report explaining how the assessment was carried out. The report should describe what assumptions were made and find one of the following conclusions* (Envt Agency, 2010):

► nothing needs to be done about the soil contamination based on your assessment

► you have enough information to take action to deal with pollutant linkages in line with soil contaminants (*it is not a matter of total soil contaminant but of source-exposure pathways-receptors and characterization of adverse effects on biological receptors*) – if this happens you should proceed to a review of the best way to take action (known as an '**option appraisal**')

► there is not enough information to decide what should happen next - if this happens you should carry out further assessment, at the next level of complexity where necessary, e.g. if a generic quantitative risk assessment was inconclusive you should do a detailed quantitative risk assessment.

How to carry out a preliminary risk assessment

● A preliminary risk assessment includes the following steps:

► decide what your assessment aims are, e.g. reducing the risk of possible harm in the future, mitigate the pollutant linkages that are already happened, test if the future land use chosen is at risks

► get information about the site

► get information about the soil contamination and other (potential) sources in line with pollutant linkages

► use the information you've got about the site and the contamination to study the risks and estimate how likely and harmful the risks are; you should compare the soil contamination and pollutant linkages in relation to the current uses, for the site and the surroundings.

► decide what, if anything, should be done next, e.g. more detailed assessments

► create a rough outline of the situation (known as a '**conceptual model**'), e.g. a diagram including relevant information about the land, the contamination, what it can harm and how

● *After you have completed your preliminary risk assessment, you should write a report that summarizes the information. You can use the report to describe your preliminary conceptual model for the site.*

Tools for risk assessment in France

- Visit of the site: http://www.installationsclassees.developpement-durable.gouv.fr/IMG/pdf/Visite.pdf
- Site assessment: documentary studies, investigation on the site
http://www.installationsclassees.developpement-durable.gouv.fr/IMG/pdf/Diagnostics_du_site-2.pdf
- Conceptual and operating models:
http://www.installationsclassees.developpement-durable.gouv.fr/IMG/pdf/Schema_Conceptuel.pdf
http://ssp-infoterre.brgm.fr/schema-conceptuel

The operating model integrates the monitoring results, allowing to pass from the "static" inventory, delivered by the conceptual model, to a dynamic vision of the management set up by integrating the results of the environmental monitoring.

- The interpretation of the state of environments - Description – Grid of calculation
http://www.installationsclassees.developpement-durable.gouv.fr/IMG/pdf/Schema_Conceptuel.pdf
http://ssp-infoterre.brgm.fr/iem

exemples:
how to build a conceptual model : http://www.installationsclassees.developpement-durable.gouv.fr/IMG/pdf/7--construction_schema.pdf
danger identification : http://www.installationsclassees.developpement-durable.gouv.fr/IMG/pdf/6-identif_dangers.pdf

- Development of Cost-Benefit Assessments adapted to the management contexts of polluted sites and soils
- Residual risk assessment
- Control and management of pollutant impacts on groundwater quality
- Groundwater quality monitoring applied to ICPEs and polluted sites
- Ordering Guide
- Guide for implementing the restrictions of use applicable to polluted sites and soils
- Guide for court administrators, court agents and classified facilities inspectors
- Guide to constructive measures for use in the field of polluted sites and soils
- Guide for off-site reclamation of excavated soil from sites and potentially polluted soils in development projects
http://www.upds.org/images/stories/gt_terres_excavees/2017-11-Guide_Valorisation_TEX_SSP.pdf
- Nature of petroleum products and aging origin: attempt to identify the source accounting for impacts and analyzing the approximate age of spills
Management of sites potentially polluted by radioactive substances

List of supporting documents

- Generic criteria for soil quality and management of site-specific management: issues, advantages and disadvantages in the French context

Characterization of the state of soils, waters and plants in the environment of industrial installations - Use of the local reference environment

Measures and Models: issues, advantages and disadvantages in the context of managing polluted sites

Existing databases on soil quality: content and use in the management of polluted soils

Summary of regulatory values for chemical substances, in force for water, foodstuffs and the air in France on December 31, 2017

French site for technical information: http://www.installationsclassees.developpement-durable.gouv.fr/Journees-Techniques.html#JT14

Tools for risk assessment in Spain

For the Basque Country

Volumen 4: Análisis de riesgos para la salud humana y los ecosistemas (1,16 Mb)

Volumen 5. Análisis de riesgos: migración y seguimiento de contaminantes en el suelo y en las aguas subterráneas (9,25 Mb)

Tools for risk assessment in Portugal

Visit of the site https://www.apambiente.pt/index.php?ref=17&subref=157&sub2ref=380

Guide for the Assessment of Imminent Threats and Environmental Damages Environmental Liability. The Environmental Protection Agency of Portugal. The Ministry of Agriculture, the Sea, the Environment and Territorial Planning ,October 2011 http://ec.europa.eu/environment/legal/liability/pdf/eld_guidance/portugal.pdf

List of supporting documents:

- APA (2015) –Projeto legislativo relativo Prevenção da Contaminação e Remediação dos Solos (PRoSolos). Establish the legal regime for the prevention and remediation of contaminated soils, safeguarding the environment and human health http://participa.pt/consulta.jsp?loadP=820
- https://docplayer.com.br/53378470-Principais-aspetos-do-projeto-lei-prosolos-prevencao-da-contaminacao-e-remediacao-do-solo-inv-celeste-jorge-lnec-e-cpga.html
- Guia metodológico para a identificação de novos passivos ambientais
- Guias Metodológicos para a Elaboração de Estudos de Impacte Ambiental
- Portaria n.º 172/2014 de 5 de setembro, que estabelece a composição, o modo de funcionamento e as atribuições do Conselho Consultivo de Avaliação de Impacte Ambiental
- Portarias n.º 398/2015 e n.º 399/2015, de 5 de novembro, que estabelecem os elementos que devem instruir os procedimentos ambientais previstos no regime de Licenciamento Único de Ambiente, para a atividade pecuária e para as atividades industriais ou similares a industriais (operações de gestão de resíduos e centrais termoelétricas, exceto centrais solares), respetivamente

Rodrigues SM, Pereira ME, Ferreira da Silva E, Hursthouse AS, Duarte AS 2009. A review of regulatory decisions for environmental protection: Part I — Challenges in the implementation of national soil policies. Environment International, 35,202-213. https://doi.org/10.1016/j.envint.2008.08.007

Rodrigues SM, Pereira ME, Ferreira da Silva E, Hursthouse AS, Duarte AC 2009. A review of regulatory decisions for environmental protection: Part II—The case-study of contaminated land management in Portugal. Environment International, 35, 214-225. https://doi.org/10.1016/j.envint.2008.08.012

http://ec.europa.eu/environment/eir/pdf/report_pt_en.pdf

Antunes IMHR, Gomes MEP, Neiva AMR, Carvalho PCS, Santos ACT 2016. Potential risk assessment in stream sediments, soils and waters after remediation in an abandoned W > Sn mine (NE Portugal). Ecotoxicology and Environmental Safety, 133, 135–145.

Antunes SC, Castro BB, Moreira M, Goncalves F, Pereira R 2013. Community-level effects in edaphic fauna from an abandoned mining area: Integration with chemical and toxicological lines of evidence. Ecotoxicol. Environ. Saf, 88, 65–71

Antunes SC, Pereira R, Marques SM, Castro BB, Gonçalves F 2011. Impaired microbial activity caused by metal pollution: A field study in a deactivated uranium mining area. Sci Total Environ, 410-411,87-95.

Dinis MDL, Fiúza A. 2009. Methodology for Exposure and Risk Assessment in Complex Environmental Pollution Situations. In: Simeonov L.I., Hassanien M.A. (eds) Exposure and Risk Assessment of Chemical Pollution — Contemporary Methodology. NATO Science for Peace and Security Series C: Environmental Security. Springer, Dordrecht https://doi.org/10.1007/978-90-481-2335-3_7

Freitas AC, Rodrigues D, Teresa AP, Rocha-Santos, Gonçalves F, Duarte AC, Pereira R 2014. The Impact of Uranium Mine Contamination of Soils on Plant Litter Decomposition. Archives of Environmental Contamination and Toxicology, 67, 601-607 DOI: 10.1007/s00244-014-0035-5

Guillard C, Zezere J. 2012. Landslide susceptibility assessment and validation in the framework of municipal planning in Portugal: the case of Loures Municipality. Environ Manage, 50, 721-35. doi: 10.1007/s00267-012-9921-7.

Pereira R, Antunes SC, Marques SM, Gonçalves F. 2008. Contribution for tier 1 of the ecological risk assessment of Cunha Baixa uranium mine (Central Portugal): I soil chemical characterization. Sci Total Environ, 390, 377-86.

Italy: The tools for risk assessment are described in the webpage http://www.isprambiente.gov.it/it/temi/suolo-e-territorio/siti-contaminati/analisi-di-rischio

The risk assessment is reported as the tool for decision support in the management of contaminated sites. The website gives access to documents and external websites on methodologies, data bases and other useful information.

How to carry out a generic quantitative risk assessment

● *Carry out a generic quantitative risk assessment to get a more detailed understanding of the site and the contamination so you can decide what to do next. The assessment will*:

► use generic assessment criteria and assumptions to study the links between the sources, pathways and receptors

► improve your conceptual model of the site

► help you decide what further action you must take

► You should collect information using a combination of:

- ■ one or more site investigations
- ■ a review and analysis of detailed information about the site (desk research)
- ■ You should write a report that summarizes all information found from doing the generic quantitative risk assessment, including: your conclusions, how you have refined your conceptual model, any uncertainties, and what you are going to do next

How to carry out a detailed quantitative risk assessment

● *If you have done a preliminary risk assessment and potentially a generic quantitative risk assessment and you still don't have enough information to make decisions then you should do a detailed quantitative risk assessment.*

► The detailed quantitative risk assessment should proceed in a similar way to a generic quantitative risk assessment, but will be more detailed and include more site-specific data and criteria, often discovered by more thorough site investigations.

► You should write a report that records how you have completed the detailed quantitative risk assessment, how you have refined your conceptual model and your conclusions. Include in your report: information about the standards used to estimate risks and make decisions; any assumptions made; details of any uncertainties; what you're going to do next.

● recommended methodology for deriving site-specific remedial (clean up) objectives for contaminated soils or groundwater to protect the aquatic environment

- UK

Environment Agency: https://www.gov.uk/government/publications/remedial-targets-worksheet-v22a-user-manual

- FR

http://www.installationsclassees.developpement-durable.gouv.fr/Outils-de-gestion.html#tex

http://ssp-infoterre.brgm.fr/methodes-et-outils

- PT

- SP

Volumen 6: Seguridad para la investigación y recuperación de suelos contaminados (1,31 Mb)

Volumen 7. Criterios ambientales para la recuperación de ruinas industriales (1,06 Mb)

● methodology to assess the risks of contaminated land exposure for human health

- UK: https://www.gov.uk/government/publications/contaminated-land-exposure-assessment-clea-tool

- FR: http://www.installationsclassees.developpement-durable.gouv.fr/Outils-de-gestion.html#tex

- PT

Rodrigues SM, Cruz N, Carvalho L, Duarte AC, Pereira E, Boim AGF, Alleoni LRF, Römkens PFAM 2018. Evaluation of a Single Extraction Test to Estimate the Human Oral Bioaccessibility of Potentially Toxic Elements in Soils. Science of the Total Environment, 635,188-202

Rodrigues S.M., Trindade T., Duarte A.C., Pereira E., Koopmans G.F., Romkens P.F.A.M. (2016). A framework to measure the availability of engineered nanoparticles in soils: Trends in soil tests and analytical tools. Trac-trends In Analytical Chemistry, 75, 129-140.

Monteiro R.J.R., Rodrigues S.M., Cruz N., Henriques B., Duarte A.C., Romkens P.F.A.M., Pereira E. (2016). Advantages and limitations of chemical extraction tests to predict mercury soil-plant transfer in soil risk evaluations. Environmental Science And Pollution Research, 23, 14327-14337.

- SP

Italy: The tools for risk assessment are described in the webpage http://www.isprambiente.gov.it/it/temi/suolo-e-territorio/siti-contaminati/analisi-di-rischio

The risk assessment is reported as the tool for decision support in the management of contaminated sites. The website gives access to documents and external websites on methodologies, data bases and other useful information.

Regulations/ National strategies

To accurately implement regulations a regulatory system coordinated across the national and local levels, avoiding duplication of efforts, conflicting environmental management and corruption.

When redefining roles and responsibilities, environmental enforcement and environmental licensing responsibilities must be separated to avoid opportunities for conflict of interest.

Screening values, i.e. pre-determined substance concentrations for soil or groundwater that represent threshold values designed to protect human health and environmental receptors from contaminant exposure, above which further risk assessment may be required, are necessary.

- FR: Screening values for metal(loid)s in French soils were reported by Baize (1997) and Baize (http://www.denis-baize.fr/etm/webetmbi.html). They can be fit for purpose, i.e. land use.

A new database is developed for French urban soils: http://www.bdsolu.fr/

Other screening values in France

- monitoring of groundwater quality (for polluted sites)

http://ssp-infoterre.brgm.fr/surveillance-qualite-eaux-souterraines-appliquee-aux-icpe-sites-pollues

Maximum permitted concentrations for chemical compounds in water, food and air

http://ssp-infoterre.brgm.fr/synthese-valeurs-reglementaires-eau-denrees-air

PT

Ávila PF, Ferreira da Silva E, Candeias C. 2017. Health risk assessment through consumption of vegetables rich in heavy metals: the case study of the surrounding villages from Panasqueira mine, Central Portugal. Environ Geochem Health, 39, 565–589.

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Candeias C, Ávila P, Coelho P, Teixeira JP 2018. Mining Activities: Health Impacts. Reference Module. In: Earth Systems and Environmental Sciences, Encyclopedia of Environmental Health, 2nd edition. ISBN: 978-0-12-409548-9.

Candeias C, Ferreira da Silva E, Ávila PF, Teixeira JP. 2014. Identifying sources and assessing potential risk of exposure to heavy metals and hazardous materials in mining areas: the case study of Panasqueira mine (Central Portugal) as an example. Geosciences, 4, 240-268.

Candeias C, Ávila PF, Ferreira da Silva E, Durães N, Ferreira A, Teixeira JP 2015. Water rock interaction and geochemical processes in surface waters influenced by tailings impoundments: The case study of Panasqueira

Mine (central Portugal), impact and threats to the ecosystems and human health in rural communities. Water Air and Soil Pollut, 226, 23

Coelho P, García-Lestón J, Costa S, Costa C, Silva S, Fuchs D, Geisler S, Dall'Armi V, Zoffoli R, Bonassi S, Pásaro E, Laffon B, Teixeira JP. 2014. Immunological alterations in individuals exposed to metal(loid)s in the Panasqueira mining area, Central Portugal. Sci Total Environ, 15, 475:1-7.

Coelho P, Costa S, Silva S, Walter A, Ranville J, Sousa AC, Costa C, Coelho M, García-Lestón J, Pastorinho MR, Laffon B, Pásaro E, Harrington C, Taylor A, Teixeira JP. 2012. Metal(loid) levels in biological matrices from human populations exposed to mining contamination--Panasqueira Mine (Portugal). J Toxicol Environ Health A, 75, 893-908.

Coelho PC, García-Lestón J, Silva SP, da Costa CS, da Costa SC, Coelho MI, Lage BL, Mendez EP, Teixeira JP. 2011. Geno- and immunotoxic effects on populations living near a mine: a case study of Panasqueira mine in Portugal. J Toxicol Environ Health A. 74, 1076-86.

Coelho P, García-Lestón J, Costa S, Costa C, Silva S, Dall'Armi V, Zoffoli R, Bonassi S, de Lima JP, Gaspar JF, Pásaro E, Laffon B, Teixeira JP. 2013. Genotoxic effect of exposure to metal(loid)s. A molecular epidemiology survey of populations living and working in Panasqueira mine area, Portugal. Environ Int, 60,163-70.

Pereira R, Ribeiro R, Gonçalves F. 2004. Scalp hair analysis as a tool in assessing human exposure to heavy metals (S. Domingos mine, Portugal). Sci Total Environ, 327, 81-92.

Pereira R, Barbosa S, Carvalho FP. 2014. Uranium mining in Portugal: a review of the environmental legacies of the largest mines and environmental and human health impacts. Environ Geochem Health, 36, 285-301.

Maximum permitted concentrations for chemical compounds in food and residual sludges applied to agricultural soils

- Decree-Law n.º 276/2009 de 2 de Outubro https://dre.pt/application/conteudo/490974
- http://www.dgv.min-agricultura.pt/portal/page/portal/DGV/genericos?generico=5938110&cboui=5938110

SP

Italy: a National database for metal concentration in soils is not available. There are many efforts at Regional level. For instance in Emilia Romagna (http://ambiente.regione.emilia-romagna.it/geologia/cartografia/webgis-banchedati/banca-dati-dei-suoli) a great amount of data is made publicly available. In Lombardia a webpage gives access to several types of environmental data: http://www.arpalombardia.it/Pages/Ricerca-Dati-ed-Indicatori.aspx

Therefore, the amount and quality of data is still variable from region to region.

other countries:

In Colombia, there are thematic regulations, including norms for solid waste, soil as a resource, mining activities and policies for land management and a National Development Plan (2010–14) with targets and measures to promote environmental sustainability and risk prevention (Arias-Espagna et al 2018). Its MESD is working on regulation and the design of technical instruments for the management of environmental liabilities in Colombia, including methodologies in how to develop remediation processes in contaminant sites (MADS, 2017). Colombia has joined the Red Latinoamericana de prevención y gestión de sitios contaminados (ReLASC), which is a regional (Latino American region) net initiative supported and maintained by private and public organisations aimed to foment the production, distribution and exchange of knowledge in the area of prevention, management and rehabilitation of contaminated sites (Arias-Espagna et al 2018).

Management of soil contamination – Options appraisal

● *Deciding how to manage the pollutant linkages, here related to the soil contaminants, is called an 'options appraisal'. Managing the pollutant linkages is known as remediation.*

● *How you choose to remediate the pollutant linkages induced by the concentration and chemical speciation of soil contaminants will usually involve identifying possible options, assessing them in depth and then deciding on your remediation strategy. Relevant factors include:*

► if one or any combination of solutions can be used on the site, e.g. because of where the site is, how big it is and how easy it is access

► if there's any way to prove the chosen solution or solutions will work, e.g. because it's been proven to prevent or reduce contamination in similar situations elsewhere

► how long it will take for the solutions to reduce or prevent pollutant linkages

► how much it'll cost

► if the solution or solutions will get the approval of everyone with an interest in the land

► getting all the legal permissions and approvals needed to do the work - what you need will vary depending on the site and the contamination

►how long the solution will work for and if that suits what the site's being used for or is going to be used for

● Write a report that summarizes the solutions you've chosen and why - this is your '**remediation strategy**'.

Gentle remediation options (GRO)

Sustainable remediation can be defined as: "the practice of demonstrating, in terms of environmental, economic and social indicators, that the benefit of undertaking remediation is higher than its impact, and that the optimum remediation solution is selected through the use of a balanced decision-making process"(CL:AIRE, 2010; Cundy et al 2017; Arias-Espagna et al 2018)

GROs have been defined as risk management solutions that result in a net gain (or at least no gross reduction) in soil functions as well as achieving effective risk management (Cundy et al., 2013). They encompass many technologies, including the use of plant (phyto-), fungi (myco-), and/or bacteria-based methods, with or without chemical additives or soil amendments, for reducing contaminant transfer to local receptors by extraction, transformation, or degradation of contaminants, or by in-situ stabilization (using biological and/or chemical processes).

Use of GRO aims at disrupting the pollutant-linkages (DEFRA, 2012) either by controlling the source (e.g. extracting the contamination from the subsurface); managing the pathway(s) (e.g. preventing migration of contamination); protecting the receptor(s) (e.g. planning or institutional controls to avoid sensitive land uses). These options can be used separately or in combination (Cundy et al., 2013).

Plant (phyto)-based GROs are described in Table 1.

As the treated soil remains unsealed, GROs are highly applicable to soft-end use for a site, e.g. for urban or community park-land, biomass generation etc. (Mench et al., 2009; Fässler et al., 2010; Bert et al., 2012a; Evangelou et al., 2012, 2015; HOMBRE, 2013; Kidd et al., 2015; Marchand et al., 2015; Robinson et al., 2015 ; Touceda et al 2017 ; Quintela-Sabaris et al 2017).

Depending on the specific site situation, GROs can have lower deployment costs than conventional remediation technologies (Vangronsveld et al., 2009; Kuppusamy et al., 2016a, b).

GROs can also contribute to sustainable remediation strategies, by providing a broad range of wider economic, social and environmental benefits (e.g. economic returns through biomass production; restoration of plant, microbial, and animal communities; water filtration and runoff and drainage management; amenity and recreation (Vangronsveld et al., 1995a, 2009; Witters et al., 2012; Cundy et al., 2013, 2015, 2016; Bert et al. 2017).

Phytoremediation options used in the phytomanagement may provide a range of sustainability benefits compared to other methods for remediation of contaminated sites including lower costs, environmental benefits such as reduced greenhouse gas emissions and waste generation, the biomass harvested can be used by various biomass processing technologies and sectors, and appropriate biomass cultivation can improve soil functions and underlying ecosystem services such as plant and microbe biodiversity, water quality, erosion control, etc. (Gomes, 2012; Suer and Andersson-Skold, 2011; Witters et al., 2012, Bardos et al., 2011; Suer and Andersson-Skold, 2011 ; Chalot et al., 2012; Delplanque et al., 2013; Simek et al. 2017; Bert et al. 2017; Mench et al 2018; Burges et al 2017).

The onsite application of GROs is expanding, particularly in Europe and for metal(loid)-contaminated sites, but still limited as compared to conventional options (Vangronsveld et al., 2009; Mench et al., 2010; Kidd et al 2015; Quintela-Sabaris et al 2017). This is due to a number of perceived (or actual) barriers or impediments related to technical issues and stakeholder perceptions (Bert et al; Cundy et al 2015). For overcoming such barriers notably in South-West Europe, the PhytoSUDOE project was initiated in 2016 (with funding from the European Interreg SUDOE). It involved a network of field applications of GROs, and contributed to practical guidance for the application of GROs at metal(loid)-contaminated sites.

- FR:

Le Guide « Phytotechnologies appliquées aux sites et sols pollués. Nouveaux résultats de recherche et démonstration » (*Phytotechnologies implemented on polluted sites and soils. New results and demonstration*). Mars/March 2017. http://www.ademe.fr/sites/default/files/assets/documents/phyto_010191.pdf

Call of ADEME for researches on implementation/demonstration of GROs at French polluted sites: https://appelsaprojets.ademe.fr/aap/GESIPOL2017-34-2

List of projects funded by the ADEME in the GESIPOL programme https://www.ademe.fr/sites/default/files/assets/documents/recherche_ssp_ademe_recueil_projets_finances_mai2017.pdf

Network 'ESSORT' (supported by ADEME): http://www.transfert-recherche-ssp.ademe.fr/le_programme.htm

Tab. 1 Implementation of GRO in France

Sites	Project	GRO	References
Northern France Mazingarbe,	MisChar	Phytomanagement: Miscanthus x giganteus	Douay et al https://mischar-43.webself.net/

Brownfield MetalEurop, Agricultural field		Hemp + biochar	
MetalEurop, Agricultural field, France	Phytener		
St-Médard d'Eyrans, SW France	PhytoDEMO PhytoSUDOE	Phytomanagement - (aided)phytoextraction High yielding crops - (aided)phytostabilisation Short rotation coppice Grassland Miscanthus x giganteus Vetiver Biochar, compost, basic slags, iron grit	Mench et al http://www.phytosudoe.eu/en/s1-st-medard-deyrans-gironde-fr/ Mench et al 2018 Phytomanagement of Cu-contaminated soils by high yielding crops at a former wood preservation site: sunflower biomass and ionome, and remediation of soil functions. Frontiers Ecology Environment Agroecology and Land Use Systems (in press)
Parc aux Angéliques, Brownfield (former harbor), Bordeaux, France	PhytoSUDOE	Phytomanagement - phytostabilization + rhizodegradation Grassland ± poplars	Marchand, Mench et al http://www.phytosudoe.eu/en/s2-parc-aux-angeliques-gironde-fr/
Ochsenfeld, CRISTAL Thann, France	Phytochem	Phytomanagement Trees and schrubs	Chalot et al http://www.agence-nationale-recherche.fr/Projet-ANR-13-CDII-0005
Leforest, Northern France	Phytochem	Phytomanagement Trees and schrubs	Chalot et al http://www.agence-nationale-recherche.fr/Projet-ANR-13-CDII-0005
Pierrelay, France	Phytopop	Phytomanagement poplars	Foulon et al 2016 Chalot et al
Auby, brownfield (Pb/Zn smelter), France		Phytomanagement	Bert et al
Fresnes sur Escaut, dredged sediment, France	Phytosed Demophyto	(aided)phytostabilisation (Cu, Pb) Phytoextraction (SRC poplars, willows) (Cd, Zn)	Bert et al
Carrefour des Forges Montataire, Creil, Smelter Voie Nouvelle,	Phytoagglo (	Phytomanagement Phytoextraction (Cd, Zn) hyperaccumulators (Arabidopsis halleri) willows (Cd, Zn) phytostabilisation (Calamagrostis epigeios)	Bert et al http://www.agebio.org/IMG/pdf/Valerie_Bert_Ineris.pdf
Rive de Giers	Physafimm	Phytomanagement (aided)phytostabilisation	

http://www.transfert-recherche-ssp.ademe.fr/le_programme.htm
https://www.ademe.fr/sites/default/files/assets/documents/recherche_ssp_ademe_recueil_projets_finances_mai2017.pdf
https://appelsaprojets.ademe.fr/aap/GESIPOL2017-34-2
http://www.georisques.gouv.fr/dossiers/pollution-des-sols-sis-et-anciens-sites-industriels
http://www.georisques.gouv.fr/dossiers/sis-secteur-dinformation-sur-les-sols/donnees#/
http://www.georisques.gouv.fr/breves/les-secteurs-dinformations-des-sols-sis
http://www.brgm.fr/projet/secteurs-information-sur-sols-sis-carte-anciens-sites-industriels-casias-cadre-loi-alur
http://www.installationsclassees.developpement-durable.gouv.fr/Outils-de-gestion.html#tex
http://www.installationsclassees.developpement-durable.gouv.fr/Outils-de-gestion.html#guidesis
http://ssp-infoterre.brgm.fr/synthese-valeurs-reglementaires-eau-denrees-air
file:///C:/Users/Michel/Downloads/17-Fiche-Phytomanagement.pdf
Phytochem rapport fonal

Tab. Implementation of GRO in Basque Country, Spain

Sites	Project	GRO	References
Jundiz Site S5a	PhytoSUDOE	Phytomanagement - (aided)phytoextraction Crops (alfalfa) - (aided)phytostabilisation Short rotation coppice (poplars) Compost	Kidd et al
Jundiz Site S5b	PhytoSUDOE	Phytomanagement - (aided)phytoextraction Crops (alfalfa) - (aided)phytostabilisation Short rotation coppice (poplars) Compost	Kidd et al
Jundiz Site S6	PhytoSUDOE	Phytomanagement - (aided)phytoextraction Crops (rapeseed, faba bean, sunflower) - (aided)phytostabilisation Short rotation coppice (willows) Compost	Kidd et al
Murcia			Clemente et al

GRO in PT

Sidella S, Cosentino SL, Fernando AL, Costa J, Barbosa B. 2018. Phytoremediation of soils contaminated with lead by *Arundo donax L*. In: WASTES – Solutions, Treatments and Opportunities II Cândida Vilarinho, Fernando Castro, Maria de Lurdes Lopes (Eds). CRS Press. ISBN 978-1-138-19669-8

https://books.google.pt/books?id=26QzDwAAQBAJ&pg=PT600&lpg=PT600&dq=phytomanaged+portuguese+soils&source=bl&ots=rPviO3ca3X&sig=ZQ1YZCJt0zKbDz9T90rtdi_bZaQ&hl=pt-BR&sa=X&ved=2ahUKEwi4hovy-bXdAhVCXsAKHbyUC0kQ6AEwBnoECAYQAQ#v=onepage&q=phytomanaged%20portuguese%20soils&f=false

Alvarenga P, de Varennes A, Cunha-Queda AC. 2014. The effect of compost treatments and a plant cover with *Agrostis tenuis* on the immobilization/mobilization of trace elements in a mine-contaminated soil. Int J Phytoremediation 16, 138-154

Prasad MNV, Pratas J, Freitas H 2005. Trace Elements in Plants and Soils of Abandoned Mines in Portugal: Significance for Phytomanagement and Biogeochemical Prospecting. In Trace Elements in the Environment, Biogeochemistry, Biotechnology, and Bioremediation, Chapter 26. MNV Prasad, Kenneth S Sajwan, Ravi Naidu (Eds). eBook ISBN 9781420032048

Sites	Project	GRO	References
Borrahla (UCP-CRP)	PhytoSUDOE	Phytomanagement	
Mina de Sao Domingos (FCTUC)	PhytoSUDOE		

IT: The latest information about GRO in Italy has been compiled in 2017 by the Italian network on contaminated sites called RECONNET. There are few examples of application of phytoremediation to some specific sites (Consiglio Nazionale delle Ricerche, 2017)[1].

[1] Tecniche di fitorimedio nella bonifica dei siti contaminati, CNR Edizioni, Roma.

http://www.reconnet.net/Docs/Tecniche%20di%20fitorimedio%20nella%20bonifica%20dei%20siti%20contaminati_RECONnet_2017.pdf

http://www.reconnet.net/Docs/Programma_completo_Corso&Workshop_v2.pdf

Sites	Project	Phytomanagement/GRO	References
Lommel, Belgium		Phytomanagement	Vangronsveld et al
Overpelt, Belgium		Phytomanagement	Vangronsveld et al
Ford, Genk, Belgium		Poplars + grassland	Vangronsveld et al
Poland			Szulc et al 2010 ; Rutkowska et al 2010, 2013, 2015
St Helen, UK			Lepp et al
China		Phytomanagement All GROs	https://www.reuters.com/article/us-china-environment-soil-idUSKCN0YM0YO

Rutkowska B., Szulc W., Bomze K., Gozdowski D., Spychaj-Fabisiak E. 2015. Soil factors affecting solubility and mobility of zinc in contaminated soils. International Journal of Environmental Science and Technology, Vol. 12, nr 5: 1687-1694.
Rutkowska B., Szulc W., Bomze K. 2013. Effects of soil properties on copper speciation in soil solution. Journal of Elementology, Vol. 18, nr 4: 695-703.
Rutkowska B., Szulc W., Bomze K. 2013. Plant availability of zinc in differentiated soil conditions. Fres. Environ. Bull. 9: 2542-2546.
Rutkowska B., Szulc W., Bomze K., Felczyński K. 2010. Usefulness of different extraction solutions for determination of plant availability of heavy metals. Ecological Chemistry and Engineering (seria A) 17, No 4-5: 483-489.
Rutkowska B., Szulc W., Łabętowicz J., Pikuła D. 2010. Bioaccumulation index and contamination index as criteria for assessment of accumulation of copper and zinc in biomass of pasture plants. Fresenius Environmental Bulletin 19, No 4: 620-623.
Szulc W., **Rutkowska B**., Łabętowicz J., Pikuła D. 2010. Tolerance index as indicator of plant sensitivity to soil pollution with heavy metals in agricultural ecosystems. Fresenius Environmental Bulletin. Vol. 19, No 2a: 397-400.

We summarize works on the use of GROs in achieving effective risk management along contaminant linkages, and the wider benefits that GROs have to offer contaminated land (and brownfield) restoration, for soft reuses in particular.

Challenges to the adoption of GROs in contaminated land management

The main barriers to widespread GRO application, in Europe and more widely, derive from a general focus of the remediation sector on remediation for critical risks or to rapidly return smaller urban brownfield sites to productive use (Cundy et al., 2013). This focus has tended to exclude GROs, which are perceived as slow and more suited to large area problems (Puschenreiter and the SUMATECS consortium, 2009). A lack of convincing pilot applications, and legal frameworks which predicate removal or destruction of contaminants to reach generic soil concentration targets, also pose significant barriers (Puschenreiter and the SUMATECS consortium 2009; Vangronsveld et al. 2009; Onwubuya et al. 2009; Cundy et al. 2013):

- Stakeholders (site owners, planners, consultants, regulators, local community, investors, insurers, etc.) may lack awareness of and/ or confidence in the application of GROs.

- There is uncertainty relating to the required time-scales for GROs, and their long-term effectiveness as risk management methods (e.g. Puschenreiter and the SUMATECS consortium, 2009).

[1] Tecniche di fitorimedio nella bonifica dei siti contaminati, CNR Edizioni, Roma.

- (Within Europe at least) GROs services are offered by relatively few consultants and contractors, which has limited their availability.

-There is limited awareness of the role of GROs as practical site solutions.

A questionnaire-based survey of stakeholder perceptions of GROs, carried out in the EU SUMATECS project in 2008, assessed reasons for hindrance in the wider uptake of gentle remediation options (Puschenreiter and the SUMATECS consortium, 2009; Cundy et al 2016; Bert et al). While GROs were known to most respondents (87% of respondents) they were rarely applied, with perceived disadvantages in the need for long-term monitoring and a lack of applicability for some types of sites and contaminants. Lack of knowledge, experience and convincing pilot projects were considered the main obstacles for more general application of gentle remediation technologies. Kennen and Kirkwood (2015) note similar obstacles, and discuss further (historical) issues whereby a huge surge of interest in phytotechnologies in the 1990s was followed by mixed performances in the field (due to application at unsuitable sites, or that implementation occurred before the supporting science was substantiated), causing a crash in stakeholder confidence in GROs which is only slowly being recovered.

Limitations

• lack of adequately trained and experienced personnel who understand the technical aspects of contaminated land risk assessment and management,

• weak and ambiguous definition for contaminated land,

• scarce funding to support the assessment and management of contamination,

• application of existing regulations

Phytoremediation vs. Phytomanagement

Some opinions reported in Anderson et al (2014) can be challenged by some recent pilot-scale demonstrations

- *'phytoremediation has failed to find widespread adoption in practice. This may due to difficulties with phytoextraction (the most commonly trialed approach) since this method is relatively slow (Bardos et al., 2011; Mench et al., 2010; Van Slycken et al., 2013; Vangronsveld et al., 2009; Delplanque et al., 2013; Westcott et al., 2011)'*;

This opinion is suggested when the annual metal(loid) removal by the harvested biomass is compared to the total soil metal(loid). But in the risk-based management approach, it must be compared to the labile pools of metal(loid)s in excess in the contaminated soils and the assessment of the pollutant linkages. Efficiency of bioavailable contaminant stripping is supported by Herzig et al (2015), Kidd et al (2015) and Mench et al (2018). Moreover as the land use purpose is to produce biomass for the processing technologies, the timescale is not the first priority.

'*the extraction effect is largely limited to the rooting depth of the plants and the biomass produced may be enriched in potentially toxic elements (PTE), and may be designated as a "waste" thus reducing its economic value (Bardos et al., 2001; Haensler, 2003; (Marmiroli and McCutcheon, 2004; Mench et al., 2010; Suthersan, 2002; Vangronsveld et al., 2009),*

- this is site-specific (soil type, porosity, chemical speciation, etc.) and depends on pollutant linkages; the metal(loid) phytoextraction to screening or trigger values is not a main target: if the phytomanagement is based on excluders; if there is no contribution of the deep soil layers to pollutant linkages;

Roots of some trees can be used for phytostabilisation, promote evapotranspiration and decrease the plum volume

If the deep soil layers are secondary sources contributing to pollutant exposure, excavated soils can be phytomanaged using an onsite ecopile and effluents can be treated in constructed wetlands

In most cases, metal(loid)-concentrations in the harvested biomass are in the common ranges and biomass can be processed (Bosse et al 2017). For metals such as Zn, Cu, Mn, Co, etc., metal-enriched biomass is giving the opportunities to produce ecocatalysts for the biosourced (green) chemistry and production of high added value-compounds (Grison et al; Oustrière et al; Escande et al)

Both Greenland and PhytoSUDOE projects have adopted a plan of action to address these impediments and collected data from a network of long-duration GRO pilot projects at contaminated sites across Europe, evaluated standard protocols and methods for monitoring the benefits and limits, and developed a set of specific design aids (for use when GRO appear to be a viable option) to promote the appropriate use of gentle remediation options and encourage participation of (and inform) stakeholders.

The PhytoSUDOE project aimed to:

1. Assess the efficiency of GRO via long-term field trials;
2. Determine changes in soil microbe and plant communities
3. Evaluate a set of tests to assess GRO performance or “success”;
4. Enhance the efficiency of GRO (e.g. by selecting effective plants, microbial inoculants, and soil amendments, and by improving agronomic practices);
5. Develop a guide for practical application of GROs.

The project made use of long-term GRO field experiments in the Southwest Europe (Spain, France, and Portugal) and other European ones carried out in the Greenland project (Belgium, France, Sweden, Switzerland, Poland, Austria, Germany, and Spain, http://www.greenland-project.eu/), coupled with laboratory trials and stakeholder discussions, and desk reviews.

These were used to provide: operational data on the effectiveness of GRO under various contaminant and site scenarios; pilot case studies/applications for different GRO types; and technical guidance to support the design, implementation and assessment/monitoring of GRO used in the remediation strategies on a site specific level.

In practice there is a shift from phytoremediation to phytomanagement approaches, in which a long term combination of profitable site use with GROs leads gradually to the reduction of pollutant linkages and the restoration or generation of wider site services.

Create a detailed plan and do remediation – implement remediation strategy

(Environment Agency, 2010)

See:

- UK: Managing and reducing land contamination: guiding principles (GPLC) https://www.gov.uk/government/publications/managing-and-reducing-land-contamination

- FR

http://www.installationsclassees.developpement-durable.gouv.fr/Outils-de-gestion.html#tex

- PT:

Rodrigues SM, Pereira ME, Ferreira da Silva E, Hursthouse AS, Duarte AS 2009. A review of regulatory decisions for environmental protection: Part I — Challenges in the implementation of national soil policies. Environment International, 35,202-213. https://doi.org/10.1016/j.envint.2008.08.007

Rodrigues SM, Pereira ME, Ferreira da Silva E, Hursthouse AS, Duarte AC 2009. A review of regulatory decisions for environmental protection: Part II—The case-study of contaminated land management in Portugal. Environment International, 35, 214-225. https://doi.org/10.1016/j.envint.2008.08.012

http://ec.europa.eu/environment/eir/pdf/report_pt_en.pdf

- SP

● *After you've done the risk assessments and options appraisal, you should create a plan explaining how remediation is going to be carried out* (known as an '**implementation plan**').

● *Prepare the implementation plan by talking to people with an interest in the land and the regulators. It will be based on and explain how to implement the remediation strategy. You should agree the plan with people with an interest in the land and any regulators. (most success stories have involved together end-users, academics, regulators, professionals and stakeholders in a task-force)*

● *Carrying out remediation involves designing in detail how it will be done, and then doing it in a safe and effective way. It includes doing trials if needed, getting any permits or approvals and doing the remediation with appropriate supervision and checks.*

Customising GROs along contaminant linkages, and wider GRO-based site management strategies

Pilot-scale applications of effective GRO strategies (i.e. "success stories") are key in providing robust technical and practical data for GRO implementation and in engendering confidence in stakeholders, both in terms of illustrating the long-term risk management potential of GRO but also in showing how wider economic, environmental and societal benefits can be realized. Pilot sites can also be pivotal in education and training as demonstrator sites, both for specialists (e.g. regulators, contaminated land consultants) and nonspecialists.

Gentle remediation options, specifically those using plants and their associated soil microbial systems, can be applied to remove the labile (or bioavailable) pool of inorganic contaminants from a site (phytoextraction), remove or degrade organic contaminants (e.g., phytodegradation), protect water resources (e.g., rhizofiltration), or stabilize or immobilize contaminants in the subsurface (e.g., phytostabilization, in-situ immobilization/phytoexclusion) (e.g., Vangronsveld et al., 2009; Mench et al., 2010; Cundy et al., 2015, Table 1).

Many studies show the potential of GROs to provide rapid risk management via pathway control coupled with a longer term removal or immobilization/isolation of contaminants (e.g., Bert et al., 2009, 2012a; Friesl-Hanl et al., 2009; Kolbas et al., 2011; Cundy et al., 2013; Herzig et al., 2014; Kennen and Kirkwood, 2015; Janssen, 2015; Kidd et al. 2016; Mench et al. 2018). For example, within the GREENLAND and PhytoSUDOE network of sites (Table 2):

- Phytoextraction (using tobacco variants and sunflower mutants selected for their metal tolerance and phytoextraction properties) was applied to Zn-contaminated soils at a former hot dip Zn factory at Bettwiesen in eastern Switzerland. The overall results of a 5-year time series experiment showed a lowering of the labile Zn pool in the soils by 45-70%, indicating the feasibility of bioavailable zinc stripping at the site within a few years (Herzig et al., 2014).

- In the northeast of Belgium (the Campine region), an area of more than 280 km2 is historically contaminated with mainly Cd, Zn and Pb. Biomass production and metal accumulation of pre-selected tobacco clones (*Nicotiana tabacum* L.), pre-selected sunflower mutants (*Helianthus annuus* L.) and a commercial hemp (*Cannabis sativa* L.) were determined over 2 -4 years while the phytoextraction potentials of more than 200 different commercially available and experimental (designed by the Institute of Nature and Forest Research, INBO) poplar (Populus) and willow (Salix) clones in short rotation coppice (SRC) were assessed at the end of the first cutting cycle (after 4 growing seasons). The tobacco clones and the sunflower mutants were efficient extractors of Cd and Zn respectively, while the highest simultaneous extraction of Cd and Zn was observed using woody species in SRC. The estimated long remediation times (>60 years to reduce total soil Cd to Flemish guideline values) however indicated that, in this case, additional value generated from economic and (other) environmental benefits will be crucial for largescale implementation of metal phytoextraction (Janssen, 2015).

- In France, aided phytostabilisation was applied over a 6 year period on a 1ha site used for on-land disposal of Zn, Pb and Cd contaminated sediments at Fresnes-sur-Escaut in northern France. Following initial site clearance (mainly of the invasive plant Japanese knotweed), a basic mineral amendment (Optiscor™) was applied to the soil, which was then planted at high density with a commercial cultivar of grass (*Deschampsia cespitosa*) (Bert et al., 2009, 2012b). The trial showed stabilization of contaminants with effectively 100% vegetation cover (reducing soil - human contaminant linkages via direct soil exposure and dust inhalation) and a reduction in plant-metal uptake and transfer (foliar element concentration in cover grass was reduced by 60% (for Zn) and 20% (for Cd)). Metal values in plant biomass were sufficiently low to allow subsequent biomass use as compost.

- In France, bioavailable metal (Cu) stripping was assessed over a 11 year period using a sunflower/tobacco crop rotation and soil amendments (i.e. compost and dolomitic limestone, basic slags). Labile Cu pool is gradually reduced and C sequestration is increasing notably (Mench et al. 2018).

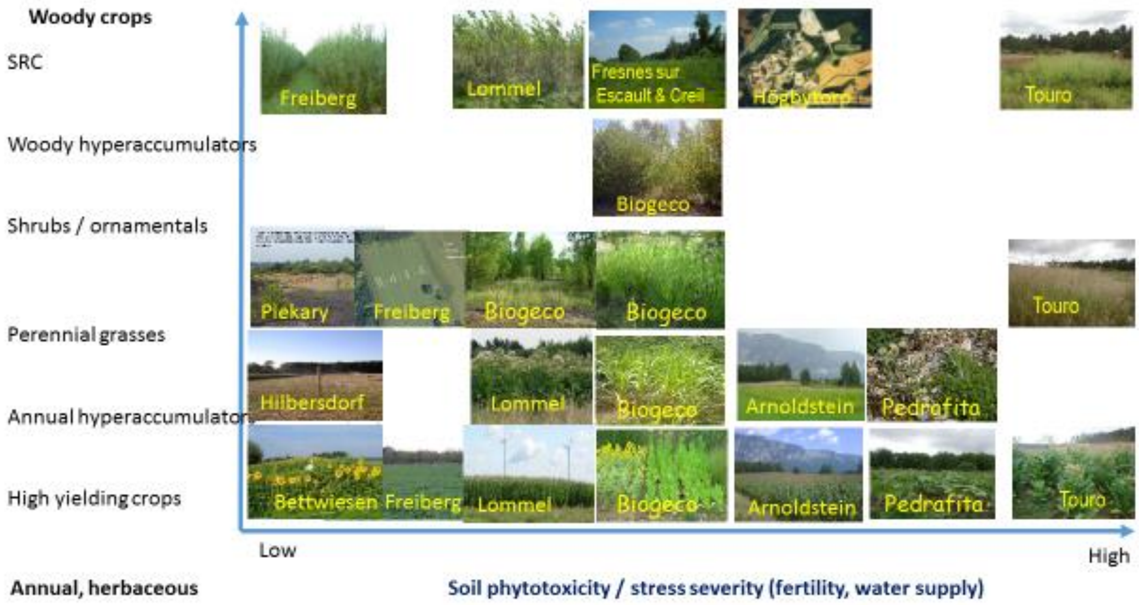
- in France, aided phytostabilisation was trialed over a 13 year period with a mixed stand of trees (i.e. poplar, willows, and false indigo; poplar/pine spp.) or grassland, iron grit singly and combined with compost.

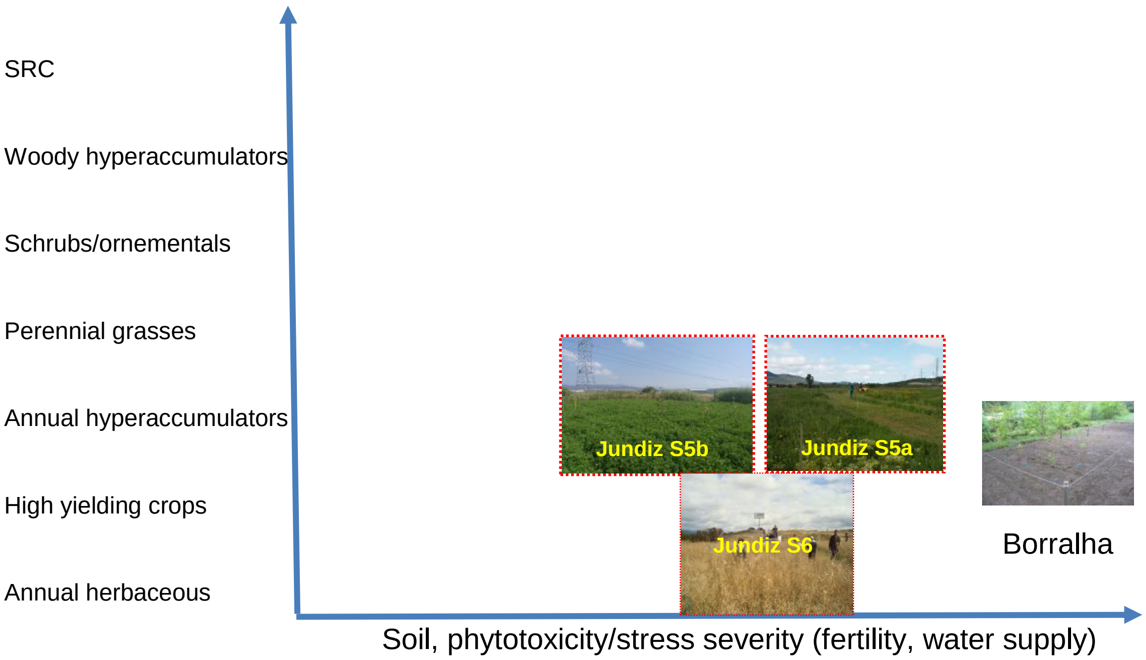
In Austria, in-situ immobilization/phytoexclusion was applied over a 13 year period at Arnoldstein (south Austria) on arable land impacted by Pb/Zn smelter emissions. Gravel sludge and iron bearing materials (red mud, 3% (w/w) ¼ 9 kg/m2 ¼ 90 t/ha) were applied as soil amendments and Cd-excluding cultivars of commercial food crops (barley, maize, and potatoes) grown, with the aim of reducing contaminant transfer from soil to plants and groundwater (Friesl-Hanl et al., 2009). Amendment addition generated a significant reduction in the labile contaminant pool in the soils (Cd could be reduced by >80%; Zn >90% and Pb >90%), while Cd uptake into barley could be reduced by >75% (compared to an accumulating cultivar). Uptake into maize silage was reduced by up to 50% for Cd, 60% for Pb, and 70% for Zn.

- in Spain, aided phytoextraction with tobacco and sunflower and aided phytostabilisation with poplars and willows, were trialed with composts and technosols (Kidd et al 2015). Phytostabilisation and rhizodegradation are assessed at Jundiz (Phytosudoe project)

- in Portugal, two field trials were established in 2016 - Borralha (S3) and São Domingos (S4), both located in abandoned mines.

At the Borralha mine, experimental plots with sunflower and poplars (inoculated and non-inoculated; intercropped with alfalfa/clover) were implemented for determining the influence of inoculation of PGPR and AMF and cropping patterns on biomass production, metal(loid) accumulation in plant parts and metal(loid) mobility in soils.
Poplars planted in the first year did not survive due to climatic conditions (heatwaves and drought), another set of poplars were established in second year.





GROs, e.g. phytoremediation options and immobilization in situ on biochars, were investigated for Hg-contaminated land in Colombia and restoring it soft end uses such as renewable energy production (Bardos et al., 2017a; b; Rodríguez et al., 2017a;b).

Site risk management by GROs can be summarized in an approach which customises or tailors GROs along contaminant linkages to manage site risk (Cundy et al. (2013). Here, methods such as phytoextraction can be used to remove the bioavailable contaminant pool at a site, or methods such as in-situ stabilization immobilize the contaminants within the soil, and so reduce the mass flux of contaminants to the receptor.

Pathway management can also be applied through rhizofiltration or phytovolatilisation options, which reduce contaminant transfer to groundwater and surrounding water bodies, while plants (as ground cover) can be used to manage receptor access to the subsurface.

Application of soil amendments (such as lime, red mud, zeolites, cyclonic ashes, iron grits and slags, or composts, biochar and other organic amendments) can reduce the bioavailability of a wide range of contaminants while simultaneously enhancing revegetation success and, thereby, protect against offsite movement of contaminants by wind and water (Vangronsveld et al., 1995a, b; 2009; Bes and Mench, 2008; Kumpiene et al., 2008; Puschenreiter and the SUMATECS consortium, 2009; Bolan et al., 2014; Jones et al., 2016).

Phytomanagement refers to a wider design and management strategy which, alongside risk management, places realization of wider (including economic) benefits at the core of site design, and uses GRO as part of integrated site management strategies rather than applying plant monocultures over extensive areas to gradually extract the bioavailable contaminant pool (although this latter approach still has clear merits under some site circumstances, e.g. Herzig et al., 2014).

Phytomanagement approaches allow the use of plant-based systems as a “holding strategy” (i.e. reducing contaminant transfer and site risk on vacant sites, while providing other benefits such as biomass generation, amenity and leisure, site value uplift of surroundings, urban climate management, ecosystem services etc., prior to development of favorable economic conditions for hard redevelopment or other site regeneration), or as part of a zoned, mixed site use, approach where GRO are applied (in combination with “hard” cover systems or conventional remediation technologies) on less contaminated areas within a site, which may better reflect site (and contaminant) heterogeneity (Neu and Müller, 2014). The large potential for GRO incorporation into urban design and landscape architecture via wetlands, riparian buffers, stabilization mats, air flow buffers, stormwater filters, interception hedgerows etc., has been discussed (Kennen and Kirkwood 2015), while a number of European examples exist which show the potential for use of GRO in site “greening” and for realization of wider site benefits as part of general site regeneration strategies (e.g. www.thelandtrust.org.uk).

GRO design and successful application is strongly site and contaminant specific: e.g. for (aided) phytoextraction to be successful, metal(loid)s must be present in chemical forms/ solubilities which roots can absorb and translocate to shoots. Conversely phytostabilization requires that these metal(loid)s can be either converted to unavailable forms for plant uptake and remain retained in the soil matrix preventing leaching losses, or captured and retained in the root systems.

Given this site and contaminant specificity, it is always recommended to implement and monitor field trials after the selection of feasible GRO before deploying the selected GRO at full implementation scale. The best conventional remediation option should also be compared in parallel to have an alternative in case of GRO failure or underperformance.

GRO application may require additional technical input from agronomists and plant specialists, institutional or planning controls to avoid shifts in land-use or land management, and a supportive local/regional regulatory framework (in cases where contaminants are stabilized in the ground, rather than removed (e.g. phytostabilization, in-situ immobilization/phytoexclusion) or where only the bioavailable contaminant fraction is removed (e.g. in phytoextraction)).

(potential) Gaps

• regulations for historic contaminated sites or mechanisms for identification,

• available framework for the clean-up of contaminated sites or guidelines in the management or assessment of contaminated sites,

• a funding mechanism to support land remediation,

• a strategy to identify and assign liability,

• public information related to remediation

• a comprehensive and overarching system to support risk-based decision making,

• processes for verification of remediation outcomes,

• record keeping methods,

• identification and incorporation of contamination issues into land use planning,

• procedures for inclusion of health and safety considerations during execution of remediation projects,

• incorporation of costs-benefit analysis and overall sustainability.

• limited number of practitioners and regulators with the skills and expertise in the phytomanagement of contaminated land

• education and training of professionals; public awareness concerning contaminated land,

Costs/liability

Cost of contaminated land management can be prohibitive and funding is a challenge. The US tackles this one by setting taxing mechanisms to chemical and petroleum industries (i.e. the Superfund) and transfer funds to clean-up projects.

Liability. law framework can be used to establish liabilities against parties responsible for contamination of the environment, and the polluter pay principle as well

FR

- This guide (BRGM, 2010) is presenting the various options for ex-situ and in situ site depollution, with (wider) benefits and limits, costs, feasibility regarding contaminants, hydrogeology, site characteristics, wastes produced, etc.

http://infoterre.brgm.fr/rapports/RP-58609-FR.pdf

- This guide (Ernst & Young for ADEME, 2013) summarizes: Utilization rates and costs of the various techniques and processes for treating polluted soils and groundwater in France. Summary of 2012 data

https://www.ademe.fr/taux-dutilisation-couts-differentes-techniques-filieres-traitement-sols-eaux-souterraines-pollues-france

- ADEME, BRGM, UPDS (2013): SelecDEPOL - an interactive tool for pre-selecting depollution techniques: www.selecdepol.fr/ *(this site is temporary unavailable due to maintenance)*

http://www.installationsclassees.developpement-durable.gouv.fr/IMG/pdf/8_SELECDEPOL_v3.pdf

SP

In the Basque Country, there are funds for polluted soil investigations (90% of the final cost) and soil restoration projects (50% of the final cost) for local administration and public entities.

2018. Suelos contaminados - Ayudas a entidades locales

http://www.euskadi.eus/ayuda_subvencion/2018/herrijasangarriak_suelos/web01-a2inguru/es/

PT

Information not available

Other countries

Wallonie: management of excavated soils. http://www.confederationconstruction.be/Portals/28/Colloque%20d%C3%A9chets/Colloque%20dechets%202013-Ayme%20ARGELES-Terres%20excavees.pdf

Benefits and opportunities

One main benefit of adopting and implementing GROs in a risk based remediation framework is that they propose sustainable solutions for restoring the usability and economic value of land. It is characterized by:

• risk reduction,

• human health protection,

• environment protection,

• reduction of aftercare requirements and

• reduction of liabilities.

Phytomanagement options can facilitate land re-use, avoidance of losing green (virgin land) and removing hazards from communities and supporting their betterment.

Realization of wider benefits

A diverse range of wider benefits can be realized when applying phyto- and other GRO-based risk management strategies.

Application of phytoremediation or use of soil amendments (as part of, or independently of, in-situ immobilization and phytostabilisation applications) may generate “core” benefits or services in the form of risk mitigation of contaminated land and groundwater, but also other benefits such as soil improvement, water resource improvement, provision of green space, renewable energy and material generation, greenhouse gas mitigation, and amenity and economic assets.

(Table 3 in Cundy et al 2016)

Many individual sites show multiple benefits.

● The Betteshanger site is a former coal-mining site located in East Kent, southeast U.K., which was regenerated between 2002 and 2011 with financial support from UK national government (BBP Regeneration, 2008). Gentle remediation strategies applied at Betteshanger involved landscaping and green cover, and the construction of a Sustainable Urban Drainage System (SUDS) which incorporated reed beds for treatment of surface run-off and foul water from new and existing built developments. In addition to risk management and water resource protection benefits, the regenerated site provides economic and amenity assets, and enhances the local environment: the major Fowlmead Country Park on its former waste tip site includes provision for walking, cycling, horse-riding and wildlife observation, while the smaller former coal-mine site accommodates a local park and up to 35,000 m2 of warehousing, industrial and office space (BBP Regeneration, 2008; Cundy et al., 2013).

● In Belgium, research at the Lommel site in the Campine region has targeted the repurposing of Cd and Zn-contaminated agricultural land for biomass and energy crops (using silage maize (Zea mays), rapeseed (Brassica napus), short rotation coppices of willow (Salix spp.) and poplar (Populus spp.)), rather than food crops (Meers et al., 2010; Ruttens et al., 2011; Witters et al., 2012; Kennen and Kirkwood, 2015). The soils in the region display a sandy texture and relatively low pH which gives an enhanced risk for uptake of these metals in crops and leaching to groundwater, resulting in food and fodder crops that often exceed European and Belgian legal threshold values for Cd in particular (Witters et al., 2012). By transitioning from food crops to biomass and energy species, the agricultural lands remain profitable to farmers (i.e. through renewable energy and materials generation and economic benefits), and contaminant linkages (e.g. soil - food pathways) are reduced, with long-term source remediation. Accounting for the marginal impact of the metals in the biomass on the energy conversion efficiency and on the potential use of the biomass and its residual (metal-enriched) products after conversion, clear carbon abatement benefits are seen with up to 14,000 kg CO_2 ha^{-1} net CO_2 avoidance for silage maize crops grown at the site (Witters et al., 2012).

● in France, at St-Médard d'Eyrans, biomass production, restoration of soil microbial communities, increase in total soil organic matter and nutrients, and decrease in labile soil Cu pool peaked for phytomanagement based on (1) sunflower/tobacco crop rotation with compost dressing every 5 years and winter crop (white and yellow clovers) (Mench et al., 2018), and (2) mixed tree stand (poplar and *Pinus sylvestris*) with a single dressing of compost and dolomitic limestone

● In France, at the Chaban-Delmas site/ Parc aux Angéliques, Bordeaux, the intercropping of poplars and grassy species led to a sustainable green cover, with no increase in labile fraction of soil metal(loid)s, and an increase in the diversity of plant community.

● In Portugal, at the Borralha mine, sunflower and poplar plants were able to grow despite the high metal(loid) levels in soils. Apparently, inoculation of PGPR and AMF did not improve plant biomass and metal(loid) mobility in soils. The intercropping of poplars and leguminous species led to a green vegetation cover.

GROs may be particularly valuable in combination with renewables generation (through biomass and biomaterial production but also through use with solar and wind power on brownfields or marginal land, USEPA, 2015a, b; Gonsalvesh et al., 2017) and with urban flood management strategies, providing rainfall interception, surface and groundwater flow management, soil erosion prevention and reduced impermeable surface area, which allows their effective integration with sustainable urban drainage (SUDS) strategies (e.g. Kennen and Kirkwood, 2015).

"Greened" urban areas may be key players in reducing urban contaminant transfer to water bodies (e.g. studies in Manchester, U.K. indicate that Zn and hydrocarbon delivery to urban drainage systems could be reduced by expanding green infrastructure, Rothwell et al., 2015).

Although GROs may be seen as "green" or more environmentally-friendly remediation options, particularly by local stakeholders (e.g. Hesske et al., 1998; Glass, 1999), they are not however automatically sustainable ; the overall economic, environmental and societal benefits depend on local site circumstances (e.g. the need for irrigation, fertilizers, fencing, weeding, etc.), the presence of local biomass processing chains, and the site design (e.g. a monoculture option vs. encouragement of a diverse site ecosystem, use of non-native or genetically modified species, etc.). It is crucial to identify and quantify the full wider value that GRO strategies may provide, so that a balanced judgement of costs and benefits can be derived. A number of studies have proposed the use of GROs to trigger land regeneration in circumstances where the economic case for intervention is marginal due to their lower deployment cost (e.g. Vangronsveld et al., 2009; Kuppusamy et al., 2016a, b) and, potentially, also by their linkage to other project services such as renewable material generation, public green space or amenity land provision, recovery of land values, etc. (e.g. Bardos et al., 2011; Andersson-Sköld et al., 2014). While some of the benefits from these services may be relatively readily quantified (e.g. economic return from biomass generation, uplift in surrounding land and housing values, and flood management value) others related to environmental and societal values may be much more difficult to monetise (e.g. Bardos et al., 2016). Some studies have highlighted the potential health and societal benefits from urban parks and green space (e.g. Victoria, 2015), which are highly compatible with GRO, and quantifying these wider benefits and value (above standard economic returns) is important in leveraging funding for GRO application and soft site end-use more widely at vacant or underutilized sites. In the context of climate changes and heat waves in big EU cities, cooling due to green and blue corridors is likely a relevant option.

Check and monitor remediation

(Environment Agency, 2010)

● *After and sometimes during remediation the work should be checked to see if it's being or has been done correctly. This is called '**verification**'. A verification plan should be produced during the design stage, saying how this will be checked, when and by whom. A **verification report** should then be produced.*

● *A plan should be produced saying what longer term monitoring or maintenance should be done, if needed. Monitoring and maintenance should be kept under review - any changes should be approved by the regulator (if needed).*

● *You must keep records explaining what was done, what happened and what decisions were taken. Reports should be written to record progress and on completion, showing that the monitoring and maintenance goals have been met.*

<u>Available tools in countries</u>

FR

● Survey/monitoring of groundwater at polluted sites
http://ssp-infoterre.brgm.fr/surveillance-qualite-eaux-souterraines-appliquee-aux-icpe-sites-pollues

SP

PT

Survey/monitoring of groundwater at polluted sites

SNIRH is a database of the National Water Resources Information System with 22639 groundwater points monitored and 7864 points have detailed information.

https://snirh.apambiente.pt/index.php?idMain=1&idItem=1.4

Costa FS, Zucco E. 2013. Monitoring and evaluation of the River basin management plans in Portugal: a contribution to the definition of a model from the case of river Ave, 8th International Conference Water Resources Management in an Interdisciplinary and Changing Context". In Proceedings of 8th International Conference "Water Resources Management in an Interdisciplinary and Changing Context", Porto.

Afonso MJ, Freitas L, Pereira P, Neves L, Guimarães L, Guilhermino L, Mayer B, Rocha F, Marques JM, Chaminé HI 2016. Environmental Groundwater Vulnerability Assessment in Urban Water Mines (Porto, NW Portugal). Water, 8, 499

https://www.eea.europa.eu/publications/92-9167-001-4/page016.html

other countries

Italy (IT): *http://www.isprambiente.gov.it/it/temi/acque-interne-e-marino-costiere/fonti-di-inquinamento/monitoraggio-e-qualita-acque*
Region Emilia Romagna (example) https://www.arpae.it/elenchi_dinamici.asp?tipo=dati_acqua&idlivello=2020

Poland (PL) – Environment Monitoring - www.gios.gov.pl/pl/stan-srodowiska/pms

Tab. Practices implemented and verification reports at the PhytoSUDOE sites: lessons & limits

Site	Site	Practices	Monitoring	Maintenance	Lessons & Limits
1	St Médard d'Eyrans: France Plots under (aided)phytoextraction Rhizodegradation of PAHs	Soil analysis Extractable metal(loid) fraction Soil pore water Lixiviation in lysimeters Plant testing in plots and/or pots Harvest of plants on site Analyses of plant parts Physiological plant parameters Soil enzyme analyses Soil microbial communities (Soil DNA extraction; NGS sequencing)	After compost incorporation 4 y; f(project) 4 y; f(project) 4 y; f(project) Each year; f(project) Each year 4 y; f(project) f(project) f (project) f(project)	Annual cropping/fertilization Compost incorporation/ 5 years Irrigation during heat waves Ploughing, weeding Preparation of plantlets in nursery Treatments vs. slugs & snails Maintenance of fences	Long-term field plots led to best demonstration Water holding capacity and water supply are key players (climate change, heat waves) Irrigation needed for annual high yielding crops to face heat waves Best soil amendments: compost and dolomitic limestone in year 1 followed by compost incorporation/ 5 y
	St Médard d'Eyrans: France Plots under (aided)phytostabilization, Rhizodegradation of PAHs	Soil analysis Extractable metal(loid) fraction Soil pore water Lixiviation in lysimeters Plant testing in pots Harvest of plants on site Physiological plant parameters analyses of plant parts Soil enzyme analyses Soil microbial communities Plant communities: species richness Insect communities: species richness	4 y; f(project) 4 y; f(project) 4 y, f(project) 4 y, f(project) f(project) 2 y f(project) 2y; f (project) f (project) f (project) 4 y, f(project) 4 y, f(project)	Irrigation in year 1 for young trees Maintenance of fences No weeding No irrigation (since years 2 or 3) No fertilization Cut every 2 years	Demonstration: plots must be larger to avoid extension of tree roots out of the plots Short rotation coppices of willows and poplars: when their root systems are established, are more resilient to water stress than annual high yielding crops. Maintenance is low; no impact of pests More successful with mycorrhizal trees from a nursery (and not unrooted cuttings) Less impacted plants by drought and contaminants: false indigo bush, willow/poplar SRC, vetiver, Miscanthus, Agrostis species
2	Parc aux Angéliques, Bordeaux, France Chaban-delmas : phytostabilisation Rhizodegradation of PAHs Borifer : aided-	Soil analysis Extractable metal(loid) fraction Soil pore water Plant testing in pots Harvest of plants on site Physiological plant parameters analyses of plant parts Plant communities: Species richness Insect communities: species richness Soil enzyme analyses Soil microbial communities	4 y; f(project) 4 y; f(project) 4 y, f(project) f(project) 2 y f(project) 2y; f (project) 4y; f (project) 4y, f (project) f (project) f (project)	Irrigation for young trees (even after 5 yr) Maintenance of fences Cut the grasses	No phytotoxicity and no impact on crawling insects despite high soil contamination Poplars suffer from water stress during summer (could be due to soil PAHs)

	phytostabilization	(Soil DNA extraction; NGS sequencing)			
3	Borralha, Portugal Phytostabilisation /Phytoextraction of Cd/Zn (by poplar leaves)	Soil analysis Extractable metal(loid) fraction Plant testing in pots Harvest of plants on site Physiological plant parameters Analyses of plant parts Plant communities: Species richness Insect communities: species richness Soil enzyme analyses Soil microbial communities (Soil DNA extraction; NGS sequencing)	2y; f(project) 2y; f(project) 1y; f(project) 2y; f(project) 1y; f(project) 2y; f (project) 1y; f(project) 1y; f(project) 1y; f(project) 1y; f(project)	Irrigation for young trees (poplars) and annual crops Cut of grasses No fertilization Weeding in non- and inoculated plots and no weeding in control plots	In year 1, poplars suffered water stress during summer (heat waves). Water holding capacity and water supply are key players (heat waves) Irrigation needed for annual high yielding crops and trees to face heat waves
4	Mina de Sao Domingos, Portugal				
5	Arinez (S5a, S5b), Spain Phytostabilisation	Soil analysis Extractable metal(loid) fraction Plant testing Physiological plant parameters Analyses of plant parts Soil enzyme analyses Soil microbial communities Plant communities: species richness Insect communities: species richness	Before and after compost incorporation, 4 y; f(project) 4 y, f(project) 4 y, f(project) 4 y, f(project) 4 y, f(project) 4 y, f(project) 4 y, f(project) 4 y, f(project) 3 y, f(project)	Initial compost incorporation Ploughing, weeding Preparation of plantlets in nursery Inoculation Irrigation during heat waves (4 y) Maintenance of fences Replanting of dead trees	Long-term field plots led to best demonstration Water holding capacity and water supply are key players (climate change, heat waves) Irrigation needed SRC in summer
6	Poligono de Jundiz (CEA, Neiker, UPV/EHU), Spain Phytostabilisation, Rhizodegradation	Soil analysis Extractable metal(loid) fraction Plant testing Physiological plant parameters Analyses of plant parts Soil enzyme analyses Soil microbial communities Plant communities: species richness Insect communities: species richness	Before and after compost incorporation, 4 y; f(project) 4 y, f(project) 4 y, f(project) 4 y, f(project) 4 y, f(project) 4 y, f(project) 4 y, f(project) 4 y, f(project) 3 y, f(project)	Initial compost incorporation Ploughing, weeding Preparation of plantlets in nursery Inoculation Irrigation during heat waves (4 y) Harvesting annual crops Seeding next rotation crop Maintenance of fences Replanting of dead trees	Long-term field plots led to best demonstration Water holding capacity and water supply are key players (climate change, heat waves) Irrigation needed SRC in summer
7	Piedrafita de Cebreiro, (CSIC/USC), Spain	Soil analysis Extractable metal(loid) fraction Soil pore water	4 y; f(project) 4 y; f(project) 4 y, f(project)		

		Plant testing in pots Harvest of plants on site Physiological plant parameters analyses of plant parts Soil enzyme analyses Soil microbial communities Plant communities: species richness Invertebrate communities: species richness	f(project) 2 y f(project) 2y; f (project) 4y; f (project) 4y, f (project) f (project) f (project)		
8	Touro (CSIC/USC) Spain	Soil analysis Extractable metal(loid) fraction Soil pore water Plant testing in pots Harvest of plants on site Physiological plant parameters analyses of plant parts Soil enzyme analyses Soil microbial communities Plant communities: species richness Invertebrate communities: species richness	4 y; f(project) 4 y; f(project) 4 y, f(project) f(project) 2 y f(project) 2y; f (project) 4y; f (project) 4y, f (project) f (project) f (project)		
9	St Sébastien d'Aigrefeuille (Carnoules) (INRA) France	Soil analysis Extractable metal(loid) fraction Plant testing in pots Physiological plant parameters analyses of plant parts	f(project) f(project) f(project) f(project) f (project)		No evidence of a beneficial influence of incorporating compost + biochar + red mud (for both eucalyptus and dwarf bean)

y: year; f(project): this operation is depending on funding by research & development projects

other sites (Poland, Belgium, Italy, etc)

	Lommel, Belgium				
	Poland	Soil analysis Extractable metal(loid) fraction Soil pore water Plant testing in plots and/or pots Harvest of plants on site	Each year	Annual cropping/fertilization	Long-term field plots led to best demonstration Maize is a relevant plant speciesfor phytoremediation

		Analyses of plant parts			
	St Helen, UK				
	Przibram, CZ				
	Krummenhennersdorf (Halsbrücke, Saxony, Germany 50° 58' 01.2" N, 13° 20' 53.0" E)				

Interreg

EUROPEAN UNION

Sudoe

PhytoSUDOE

European Regional Development Fund

RECOVERING CONTAMINATED SOILS THROUGH PHYTOMANAGEMENT IN SOUTHWEST EUROPE

El proyecto PhytoSUDOE (SOE1/P5/E0189) está financiado por el Fondo Europeo de Desarrollo Regional (Comisión Europea) a través del V programa Interreg Sudoe.

Table 1
Lessons based on the UK and USA experiences that might benefit contaminated land management in Colombia.

	UK	USA	Current practice	Recommendations
Statuary definition	Clear definition for contaminated land that makes reference to the link between Source-Pathway-and Receptor.	Clear definition for contaminated land that makes reference and highlights the importance of the link between Source-Pathway-and Receptor.	There is no existing definition for contaminated land.	Revise existing guidance to provide a statutory definition for contaminated land that refers to the Source-Pathway-Receptor model.
Structure of regulators and capacity	The local and environmental authorities are well coordinated, have a clear role and have developed standards. Moreover, are equipped with technical personnel.	The US EPA is well coordinated with a clear understanding of its roles. Moreover, the agency is sufficiently equipped with sufficient training, technical, and human resources.	Lack of periodic training and capacity building and development platforms.	Requirement for a specific agency, similar to that of US EPA, dedicated to contaminated land assessment and management. Development of guidelines that clearly define roles and responsibilities of the agency responsible for assessment and management of contaminated land.
Funding	Government funding has been reduced. Existing policy encourages voluntary remediation by private land owners.	Superfund by taxing petro-chemical and other industries. At the same time, voluntary remediation is encouraged.	Mainly relies on voluntary actions.	Incorporation of the polluter pays principle into existing legislation, including mechanisms of enforcement (e.g. for pollution events) and prioritisation approaches to deal with 'orphan sites'. In the short term, a Trust Fund (similar to US superfund) should be established with contributions from crude oil sales to fund contaminated land clean up.
Technical approach	Land use is considered in the assessment of contaminated land. Screening values of contaminants are derived based on a scientific basis.	Land use is considered in the assessment of contaminated land. Screening values of contaminants are derived based on a scientific basis.	Use of generic screening values for contaminated land screening (mainly based in international guidelines), which might be inappropriate for the Colombian environment. Technical personnel lacks the knowledge and expertise.	Develop nationally consistent methods for deriving human health and ecologically appropriate screening values that take into consideration land use (i.e. fit for purpose). Education and training of professionals by strategic international partnerships.
Liability	A structured process identifies the person responsible (known as Appropriate Person).	A structured and strict process identifies the potential responsible party (known as PRP). It also practices joint liability.	Lack of structure for the identification or allocation of liability to a polluter.	Strictly implement the polluter pays principle. Implement means to identify a polluter and allocate liability.
Incorporation of cost-benefit analysis	Incorporate social benefits and at the same time reduction of costs and environmental damage in the management and decision making of contaminated land.	Mainly focus in the reduction of environmental footprint in the management and decision making of contaminated land.	Fail to incorporate cos-benefit analysis and consequently social benefits are not maximised.	Develop a policy that incorporate net social benefit, reduce costs (i.e. economic benefits) and reduce environmental impacts into decision making.
Engagement of public and stakeholders	Public consultations are aimed at the education of the general public and create awareness (e.g. new policies, new changes in policies) related to contaminated land management policies.	Public awareness programmes are aimed at the education of the general public and stakeholders related to changes to policy and newly identified contaminated sites.	Lack of public awareness and participation in the management of contaminated land.	Increase public awareness using different mechanisms such as: short communications letters, local media, symposia and workshops in rural and urban areas to inform the public about contaminated land policies, the risks and impacts in human health and the environment.