

arag^{sun}rn



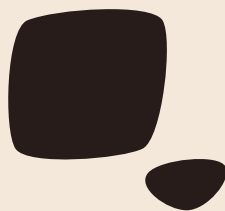
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Factsheets on the four groups
of persistent pollutants:

← Metals →	OCBs	PETCO	PFAS
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Metals



This factsheet is designed to help anyone interested in learning about the most persistent pollutants affecting local land and water.

It explains what these contaminants are, why they matter, and how landowners and other stakeholders can learn how to assess and manage them responsibly.



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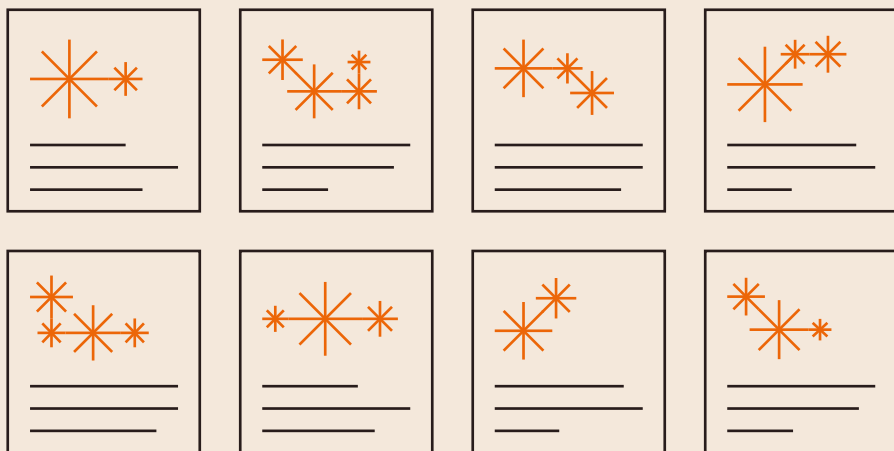
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What are these contaminants and what are they used for?

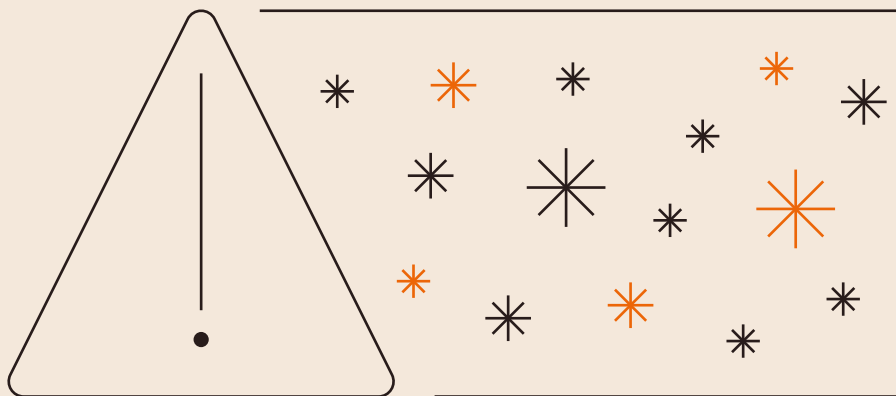
Metals and metalloids are often referred to as **heavy metals or trace elements** when discussing soil and water contamination. Examples of prioritized metals, and their chemical abbreviations, are Lead (Pb), Cadmium (Cd), Arsenic (As), Mercury (Hg), Copper (Cu), Nickel (Ni), Chromium (Cr), Antimony (Sb), and Zinc (Zn).

Main sources of pollution include mining, metal refining, fossil fuel combustion, industrial production, old pesticides and paints, sewage sludge, and waste disposal.

☀ **Lead (Pb)** is a heavy metal that does not occur in pure form in nature but is extracted from ores. It was widely used in the past in products such as leaded petrol, paints, pipes, batteries, and ammunition, as well as in some industrial additives. Today, the main pollution sources are largely historical, including residues from leaded petrol, old paint, smelters, battery manufacturing and recycling, shooting ranges, plumbing, and some fertilizers.

- ☀ **Cadmium (Cd)** is mainly a by-product of zinc and lead mining and smelting. Historically, it was used in pesticides, herbicides, wood preservatives, and certain alloys, and it is still used in semiconductors and some glass products. Pollution comes from mining and smelting activities, coal burning, use of pesticides, pressure-treated wood, and in some areas naturally elevated levels in groundwater.
- ☀ **Arsenic (As)** is a metalloid found naturally in the earth's crust and widely distributed in the environment, mainly as inorganic arsenite (As^{3+}) and arsenate (As^{5+}) or organic methylated arsenic compounds. It is used in the production of glass, pigments, wood preservatives, semiconductors, and certain pharmaceuticals. Arsenic contamination is most commonly associated with groundwater. The main sources of pollution include mining, smelting, fossil fuel combustion, phytosanitary products, and industrial discharge.
- ☀ **Mercury (Hg)** is unique as it is a liquid metal at room temperature. It is highly toxic, persistent, and can build up in the food chain, in particular in its methylated form. In the past, mercury was used in thermometers, switches, fluorescent lamps, dental amalgams, gold mining, and chlor-alkali production. Today's main pollution sources include coal combustion, artisanal gold mining, industrial emissions, waste incineration, and improper disposal of mercury-containing products.
- ☀ **Copper (Cu)** is an essential trace element for living organisms, but it becomes harmful in excess. It is widely used in electrical wiring, plumbing, roofing, and alloys such as bronze and brass, as well as in pesticides and wood preservatives. Pollution sources include mining, the metal industry, copper-based pesticides (it remains widely used in viticulture, especially organic production, where few alternatives exist for disease control), brake and tire wear, corrosion of plumbing systems, and application of sewage sludge.

- ☀ **Nickel (Ni)** is a silvery-white metal valued for its strength and resistance to corrosion. It is used in stainless steel, other alloys, batteries, coins, catalysts, and surface coatings. Main sources of pollution are mining, smelting, metal finishing, combustion of oil and coal, waste incineration, and sewage sludge.
- ☀ **Chromium (Cr)** exists in different chemical forms. Chromium (III) is needed in trace amounts, but chromium (VI) is highly toxic and carcinogenic. Chromium is used in stainless steel production, electroplating, leather tanning, pigments, and wood preservatives. Pollution comes mainly from metal processing, the tanning industry, chromate production, and industrial waste disposal.
- ☀ **Antimony (Sb)** is a metalloid used mostly in alloys and flame retardants. It is found in fireproofing for plastics and textiles, in lead alloys for batteries and ammunition, and in semiconductors. The main sources of pollution are mining, smelting, coal burning, brake wear, and industrial production.
- ☀ **Zinc (Zn)** is another essential element, but excessive concentrations are harmful. It is widely used for galvanizing steel to prevent rust, in alloys such as brass, in fertilizers and animal feed, and in pigments and batteries. Pollution mainly arises from mining, galvanizing industries, tire and brake wear, fertilizers, sewage sludge, and waste disposal.

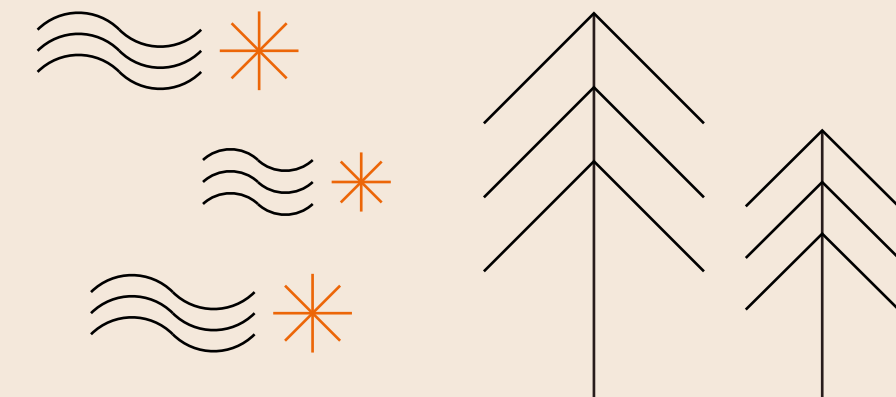


Why are we concerned?

Metals are a concern because they are toxic, persistent, and able to accumulate in living systems, **leading to long-lasting impacts on human health, ecosystems, and land use.**

Pollution with metals such as lead, cadmium, arsenic, mercury, copper, nickel, chromium, antimony, and zinc is a serious concern because these substances can harm both people and the environment. Some of them, like copper, zinc, and nickel, **are needed by living organisms in very small amounts, but at higher concentrations they become toxic.** Others, such as lead, cadmium, arsenic, and mercury, are dangerous even at low levels. They can damage vital organs, affect brain development, cause cancer, or disrupt the nervous system.

A key problem is that **metals do not break down over time.** Once released, they remain in soils, sediments, and water for decades or even centuries. They can also build up in plants, animals, and humans through the food chain. This means, for example, that mercury can accumulate in fish, cadmium can enter rice or leafy vegetables, and arsenic can contaminate groundwater used for drinking or irrigation. Beyond the risks to health, **metal pollution can harm soil quality by affecting microorganisms and plant growth,** which reduces biodiversity and productivity.



Environmental fate, transport, effects

Metals and metalloids such as lead, cadmium, arsenic, mercury, copper, nickel, chromium, antimony, and zinc are common soil, water, and sediment contaminants. Unlike organic pollutants, **they do not break down but persist in the environment**. Their risks depend on how mobile they are, how easily they accumulate in organisms, and what effects they have on ecosystems and human health. While metals cannot be degraded, **they can change form through processes** such as oxidation, reduction, or methylation. Mercury, arsenic, and lead – and sometimes cadmium – are particularly prone to methylation, which increases their bioaccumulation, while zinc does not form stable methylated compounds.

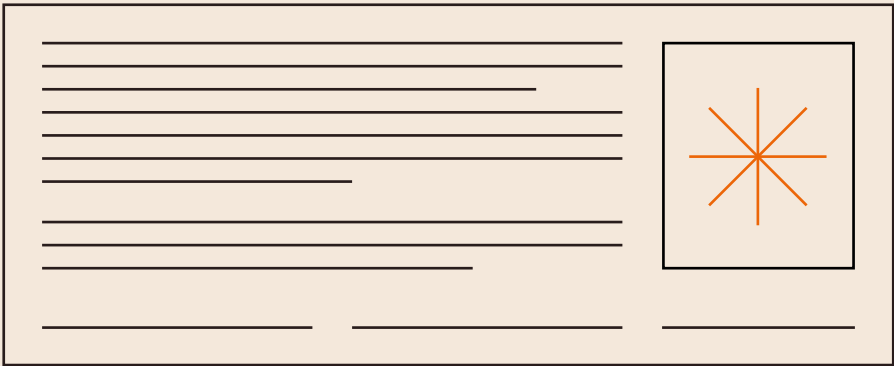
Once released, metals often bind to soil particles, sediments, or organic matter, which may reduce immediate mobility. However, **environmental conditions** such as acidity, oxygen levels, or salinity **can shift their behavior**. For example, cadmium, lead, and zinc become more mobile in acidic soils, whereas arsenic is easily mobilized in oxygen-poor groundwater. Contaminated dust is another important exposure pathway for humans.

Inhalation is often the main route of lead exposure, as fine lead-containing dust particles can be absorbed through the lungs into the bloodstream. Some metals, including mercury and cadmium, can also travel long distances in the atmosphere before depositing back to the ground, **spreading contamination far from the original source**.

Water systems are particularly vulnerable. Metals can dissolve, bind to suspended particles, and settle in sediments, which then act as long-term reservoirs. If chemical conditions change, these sediments may release metals back into the water. For example, under certain conditions, mercury can be converted by microorganisms into methylmercury, which is a highly toxic compound that accumulates in fish and poses serious health risks to humans and wildlife.

Health and ecological effects vary across metals. Lead is a potent neurotoxin, especially harmful to children, who may ingest contaminated soil while playing outside, leading for example to reduced IQ, attention deficits, and behavioral problems (e.g. irritability, aggression, impulsivity). Cadmium damages kidneys and bones and can enter the food chain through crops. Arsenic is both toxic and carcinogenic, with groundwater contamination a major global issue. Mercury, particularly in its organic form, affects brain and nervous system function and is a well-known problem in fish. Copper, nickel, and zinc are essential trace nutrients, but toxic at elevated levels, harming plants, soil microbes, and aquatic organisms. Chromium, under the highly mobile Cr(VI) form, is carcinogenic, and toxic. Antimony behaves like arsenic, though generally less mobile, and is increasingly linked to industrial emissions and brake wear.

In soils, **excess metals reduce fertility** by disturbing microbial activity and plant growth. In aquatic environments, **they disrupt fish, invertebrates, and food webs**. Because they accumulate in organisms and move up the food chain, even low-level contamination can lead to long-term risks for both ecosystems and human health.



Regulation and guidelines

European framework for soil legislation

The European Union introduced legislation on soil health in the **Soil Monitoring and Resilience Directive (SMRD)** that mandates the monitoring and assessment of soil quality. However, most threshold limit values and procedural rules are set and enforced by Member States and often at regional/local level. EU sets frameworks, principles and reporting/monitoring obligations, and **Member States translate these into national laws** (setting site-identification, screening values, risk assessment methods and mandatory remediation duties); local authorities typically implement, inspect and require remediation on the ground.

There are two common approaches used by Member States:

- ☀ **Generic screening/threshold values** (soil screening values, intervention values) that trigger further action when exceeded.
- ☀ **Risk-based site assessment** where exposure pathways and site-specific conditions determine whether remediation is required and what measures are appropriate.

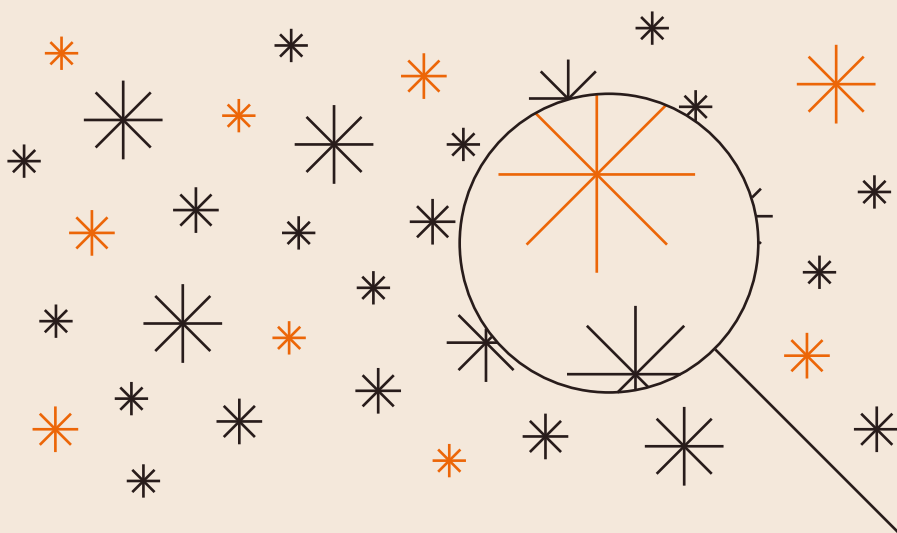
For specific Member States approaches, the specific **Member State's environment ministry** or **national environmental agency** (e.g., UK: Environment Agency; Germany: Länder Umweltämter; Sweden: Naturvårdsverket) may contain information on national soil law, contaminated-land guidance, national screening values or risk assessment protocols.

Links to other European regulations

Soil rules may be affected and can affect other EU rules such as groundwater/surface-water protection under the Water Framework Directive and dangerous substances rules, waste and landfill legislation (affecting historical waste-derived contamination), and permitting under the Industrial Emissions Directive. These links mean that **EU law can impose soil-protective outcomes** through water protection, waste rules or pollution permitting.

International frameworks and conventions

While EU and national laws provide binding rules within specific jurisdictions, **international treaties and organizations provide global standards**, obligations, and guidance that influence national regulations, enable cross-border cooperation, and address chemicals that persist and move beyond one country's borders. Examples are the Stockholm Convention on Persistent Organic Pollutants (POPs), Minamata Convention on Mercury, and the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes (including contaminated soils).

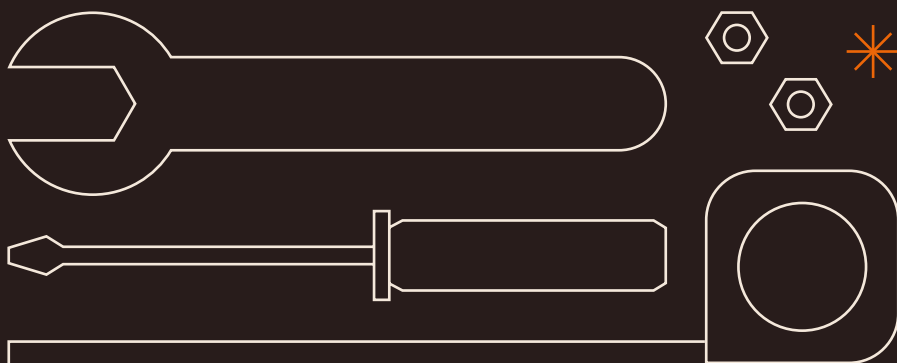


Soil testing and analysis

When investigating contaminated land or groundwater, **the way samples are taken is just as important as the laboratory analysis.** To get reliable results, samples need to be collected carefully, preserved immediately, and transported under controlled conditions. In cases where threshold values exist for a fraction of redox-active species, for example in case of Cr(VI) or methylmercury, or in cases where bioavailability or mobility of the metal contaminant is to be investigated, samples should be taken and handled with caution for preserving redox-conditions. **There are standardized methods for environmental characterization of soil and related matrices,** for example the European Committee for Standardization CEN/TC 444, with the goal of harmonizing how environmental data are collected and reported across Europe. Also, national or regional guidance might specify how and when soil or groundwater should be tested, and what analytical standards to use. Sampling protocols therefore often need to be conducted or supervised by accredited laboratories.

In the laboratory, the soil is dried, sieved, and prepared for chemical analysis. Metals are not measured directly in the soil but are extracted or digested using strong acids (such as aqua regia or nitric acid) that release the metals from the soil particles. The resulting liquid is then analysed with sensitive instruments. The two most common techniques are **ICP-MS** (Inductively Coupled Plasma Mass Spectrometry) and **ICP-OES** (Optical Emission Spectrometry). These methods can detect metals at very low concentrations and give results for many elements at once. Mercury is often measured with a specialized instrument that can detect it directly or after digestion.

Soil extraction using strong acids (such as aqua regia or nitric acid) **allow only the measurement of total or pseudo-total metal concentrations**. While essential for legal compliance, they do not reflect metal mobility or bioavailability, which are more relevant for assessing actual environmental and health risks. A more detailed and accurate assessment of risk can be achieved by measuring bioavailable or extractable metal fractions (e.g. using calcium chloride, ethylenediaminetetraacetic acid (EDTA), ammonium nitrate, or through sequential extraction procedures). **Specific methods also exist for determining individual species of certain elements**. For example, Cr(VI), can be measured after alkaline extraction followed by colorimetric analysis, and arsenic species, for example As(III) and As(V) can be separated by high performance liquid chromatography (HPLC) before ICP-MS analysis.



Remediation options

If your land is contaminated, **remediation means cleaning it up or managing the pollution**, to sufficiently reduce the risk to people, water, or the ecosystem animals and plants. Remediation does not always mean physically removing all the contaminated soil, it can also involve isolating the pollution or treating it on site. **Costs can vary widely depending on the contamination and chosen method.** The table below provides an overview of the different remediation principles together with specific methods and their advantages and limitations.





Physical removal or isolation of contaminants

Excavation:

Remove contaminated soil or sediment

Soil washing:

Separate fine, contaminated soil fractions from clean material using water/solutions

Soil flushing:

Injecting water/solutions into soil to mobilize and extract metals in situ

Stabilization/solidification:

Adding binders (cement, lime, phosphate, clays) to immobilize metals

Sorption:

Biochar/organic amendments: Added carbon-rich material increases binding capacity, reduces mobility

ReSoil:

chemical washing removes toxic metals and metalloids from soil; the residual fraction is immobilized.

Advantages:

Immediate removal, works for all metals

Reduces soil volume needing disposal

No excavation, can treat large volumes

Cost-effective, reduces mobility and exposure

Improves soil health, long-lasting immobilization

Removes metals, preserves soil, produces no wastewater, recycles reagent for improved cost-efficiency

Limitations:

High costs & high energy input, only relocate the contaminants.

Invasive & destructive

Requires excavation, treatment and handling of wash residues

Risk of spreading contamination

Does not remove metals, soil function may be lost

Effectiveness varies; metals remain in soil

On-site treatment requires excavation and cannot treat metal ores or tailings



Chemical agents transform contaminants into less harmful substances

Chemical reduction/oxidation:

Changing oxidation state to reduce toxicity/mobility (e.g. $\text{Cr(VI)} \rightarrow \text{Cr(III)}$)

Phosphate or Sulfur-based amendments:

Form insoluble metal-phosphate compounds /
Precipitation of metals as insoluble sulfides

Advantages:

- Reduces toxicity of highly hazardous metals
- Reduces mobility

Limitations:

- Site-specific effectiveness
- Effectiveness depends on soil chemistry.
- Risk of unwanted by-products



Biological processes remove, degrade, or contain contaminants

Phytoremediation:

Using plants to absorb or immobilize metals

Microbial remediation:

Microbes alter metal speciation (e.g. $\text{Cr(VI)} \rightarrow \text{Cr(III)}$)

Advantages:

Low-cost, eco-friendly, improves soil cover

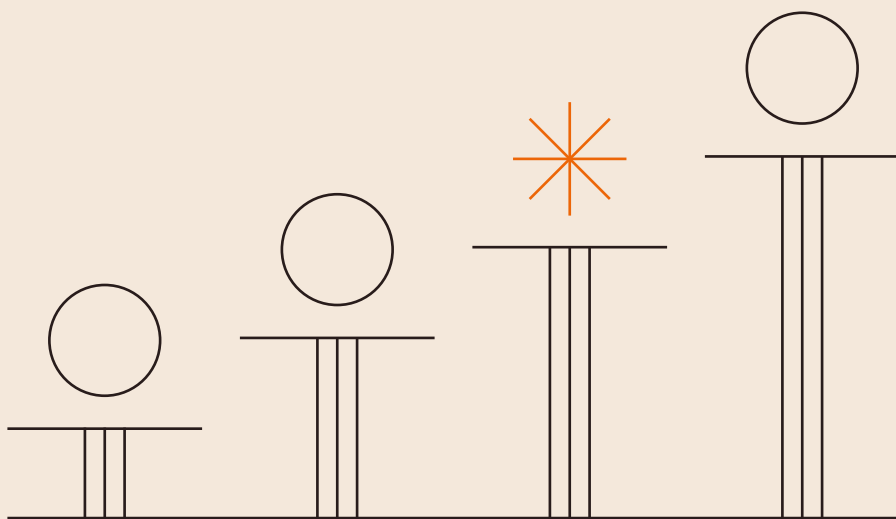
Can reduce toxicity naturally

Limitations:

Slow degradation/uptake thus long treatment time, only soil accessible to roots

Slow, sensitive to soil conditions





Initial steps to assess a potentially contaminated site

Gather information about the site

Before any work or decisions can begin it's important to build a complete picture of the site. This means gathering different kinds of information about the land itself, its history, and its surroundings. Each piece helps us understand how pollution might spread and who or what could be affected.

- ☀ **Collect site history**, such as uses, know sources of pollution, old maps, news on special events, environmental permits, as past uses often helps explain what types of pollution might be present.
- ☀ **Topographical data**, including shape of the land and location of buildings, helps predict pathways of pollution via water and air including spreading of dust.

- ☀ **Geological data** on type of soil or rock and how deep the layers are, matters since some solids trap pollution while others let it spread quickly.
- ☀ **Hydrogeology**, such as depth of water and direction of groundwater flow is important since contamination can move with groundwater and reach wells, rivers, or lakes, creating health and environmental risks.
- ☀ **Meteorological data** (climate and weather) can wash pollutants deeper into the soil or spread them to water bodies. Wind can carry dust or vapours to nearby areas.
- ☀ **Contamination data** (what is in the soil and water) show how serious the problem is and whether it poses a direct risk.
- ☀ **Surrounding exposure pathways** (how people or nature could come into contact) determines the risks. Even if pollution is present, it only becomes dangerous if it has a “pathway” to reach people, animals, or ecosystems.

Gathering of the background information should be followed by field verification – sampling of soil, groundwater, surface water, as well as on-site screening using portable instruments. This data will be the basis for the risk assessment.

Assess the economic and logistic factors



Budget:

Cost of treatment, monitoring, and long-term management.



Infrastructure:

Availability of equipment and skilled personnel.



Timeframe:

Urgency of remediation (e.g., emergency vs. long-term project).

Set the remediation goals



Containment vs. destruction:

Whether the goal is to immobilize or eliminate the contamination.



Reuse potential:

Whether the soil needs to be reused (e.g., agriculture, construction).



Risk reduction:

Immediate vs. long-term health and environmental risk mitigation.

Understand the rules and responsibilities

It is of importance to clarify **who is legally responsible for the contamination** (landowner, business provider, etc.), **who caused the contamination** and **when it may create different obligations**. Check whether the site or soil use falls under any EU directive obligations (water, industrial emissions, waste), as these also can bring binding obligations.

Most often it is the Member State's contaminated-land regime: national law, agency guidance, and any regional technical guidance on soil use and contamination, that are the most important rules to be aware of.

Some regions or municipalities have additional rules for construction, excavation, or soil movement even if national or EU rules do not explicitly require action. Certain contamination incidents may require **mandatory reporting to environmental authorities and potential restrictions on land use**.

Consult experts and find information

Remediation and restoration depend on the risk level and intended use of the land. Therefore, it is advisable to consult experts to perform risk assessments and recommend actions in line with the current legislation. Seeking expert advice early can also be cost saving, as early misguided actions can become expensive over time. Environmental consultants can help with performing basic screening for initial assessment, doing legal compliance check, and develop remediation plans. They should also be very familiar with local and national regulations and able to translate them into practical guidance for landowners.

There are many useful resources for anyone seeking more information on pollutants and soil remediation. Because knowledge in this field is constantly evolving, it is recommended to consult both national and regional knowledge hubs as well as European sources. For example, the **Common Forum** (commonforum.eu) brings together expertise and facilitates information exchange on contaminated land and groundwater management. The **EU Soil Observatory (EUSO)** (joint-research-centre.ec.europa.eu) provides soil data, supports research and innovation, and raises awareness of the importance of soils. The **European Food Safety Authority (EFSA)** (efsa.europa.eu) offers scientific advice to risk managers, especially on risks linked to the food chain.

The **European Chemical Agency (ECHA)** manages the implementation of the EU's chemicals legislation and promotes the safe use of chemicals to protect human health and the environment (echa.europa.eu).



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