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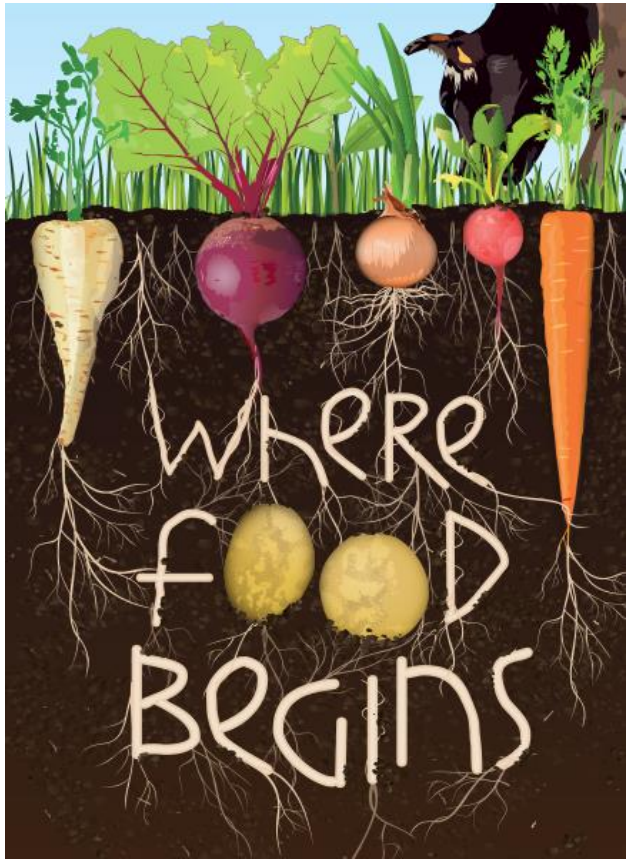
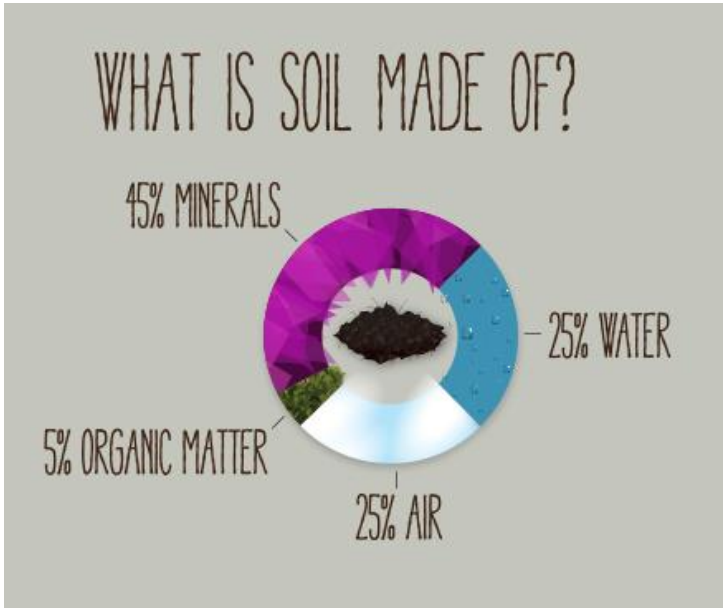
Soil contamination

Paola Adamo

Dipartimento di Agraria
Università di Napoli Federico II
paola.adamo@unina.it

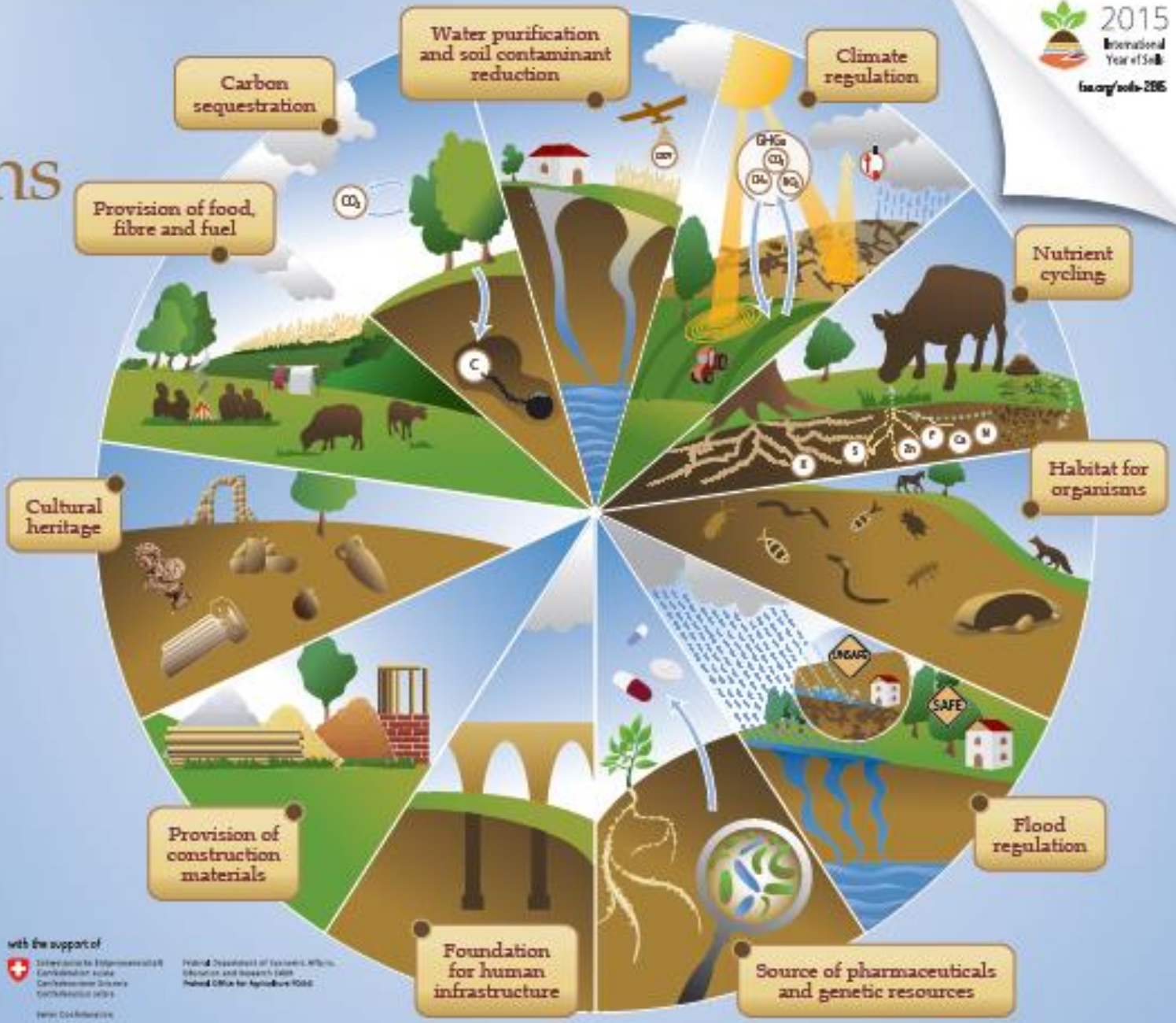
Soil is generally defined as the top layer of the earth's crust, formed by mineral particles, organic matter, water, air and living organisms. As soil formation is an extremely slow process, soil can be considered essentially as a nonrenewable resource.





Soil functions

Soils deliver ecosystem services that enable life on Earth



2015 International Year of Soils

fao.org/soils-2015

Food and Agriculture Organization of the United Nations

with the support of

Soil degradation processes or threats

Sealing

Erosion

Loss of Organic Carbon

Compaction

Salinization

floods and landslides

Pollution

Biodiversity loss

Thematic Strategy for Soil Protection (2006)

What is soil contamination?

Soil contamination and pollution mean different things even though we often use these terms to mean one thing.

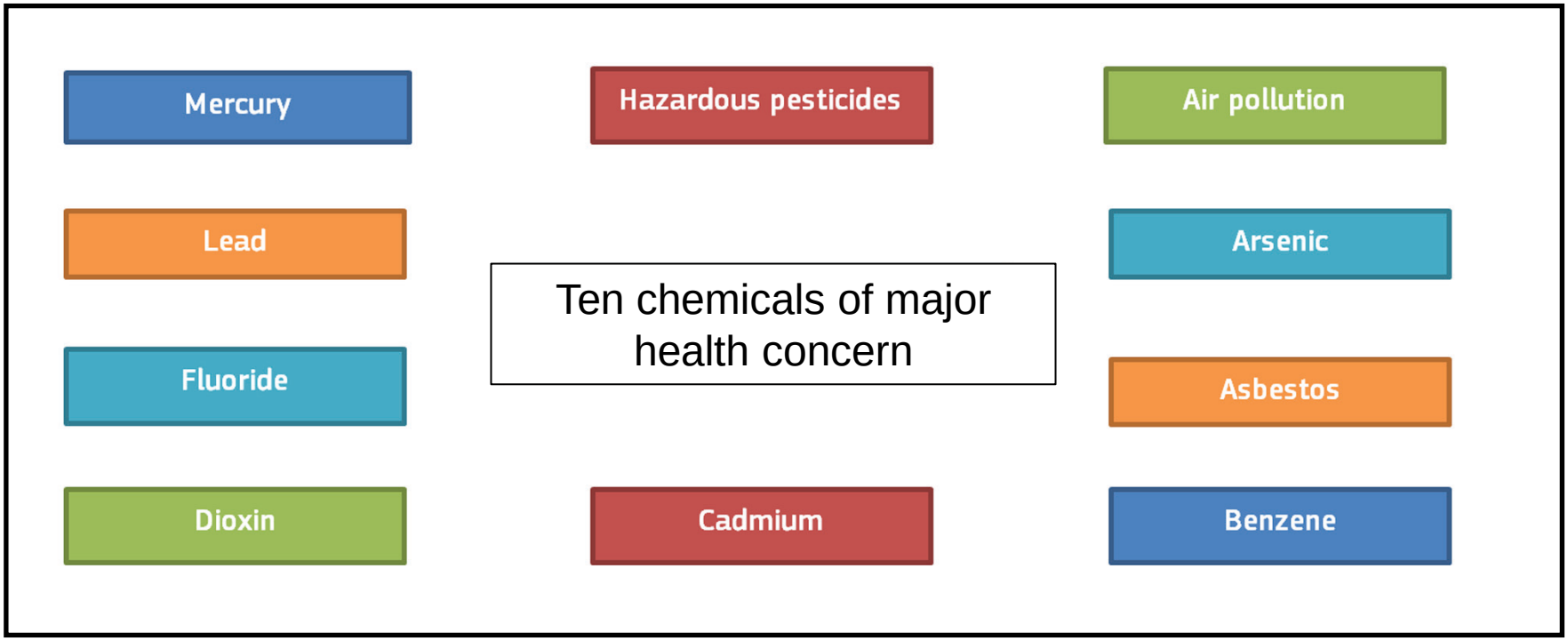
Soil pollution means the presence in soil of chemicals or substances at a **higher than normal concentration** that has adverse effects on living organisms (FAO and ITPS, 2015).

Soil contamination is when the concentration of chemicals, nutrients or elements in the soil becomes more than it normally or naturally is, as a result of human action. If this contamination goes on to harm living organisms, we can call it pollution.

Main contaminants

Inorganic: heavy metals, cyanides, fluorides, radionuclides, asbestos, …

Organic: petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides and herbicides, dioxins, ...



WHO (2013)

Human activities are the main sources of soil pollution

INDUSTRIAL

Around **50,000–100,000** chemicals are now commercially produced on a large scale and their production is projected to increase by **3.4%** yearly until **2030**

WASTE MANAGEMENT

Expanding cities are producing an ever-growing amount of municipal solid waste. **80%** of our waste is not being recycled and ends up in landfills, contaminating our soils

AGRICULTURE

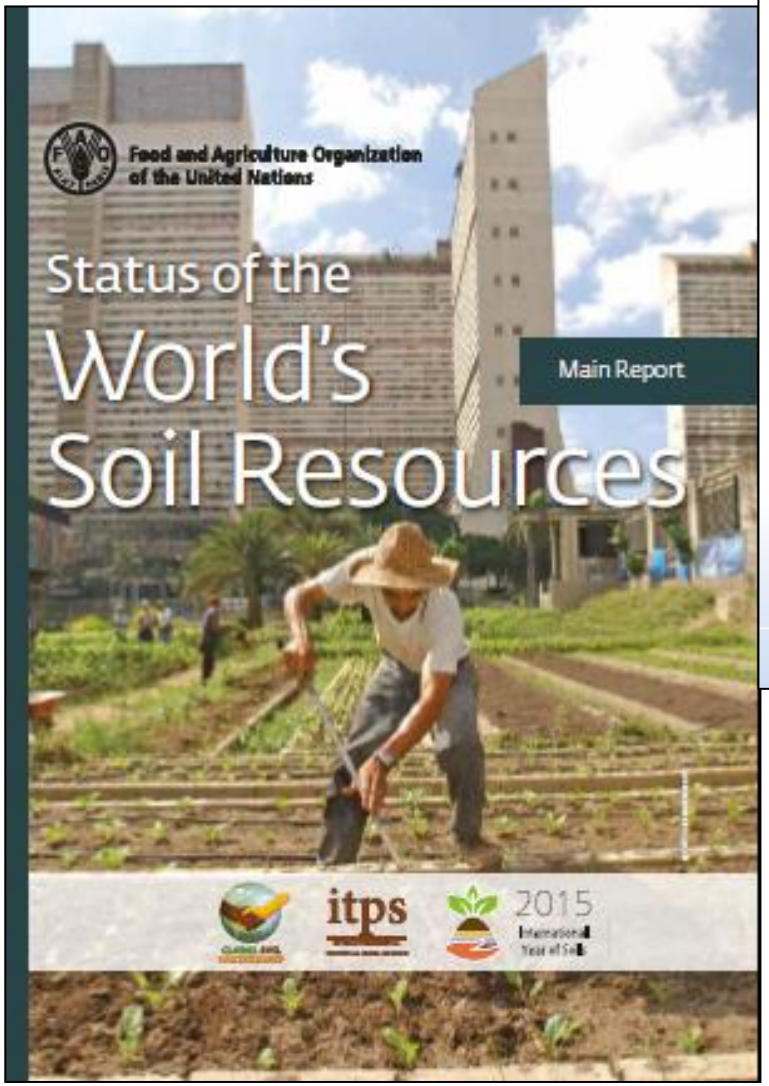
The agrochemicals market is increasing by **3.2%** every year. **58%** of agricultural soils in Europe have residues of multiple pesticides, half of them are now illegal

MINING

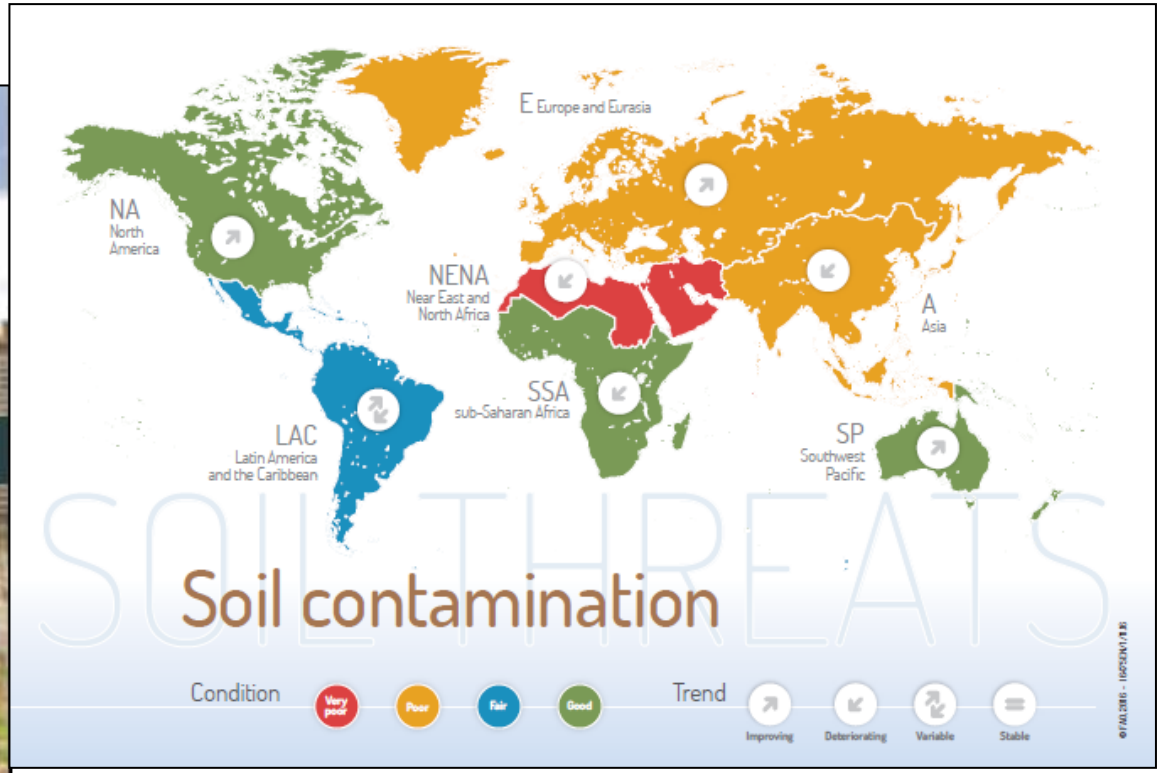
About **4 billion** people live in the **56** biggest mineral-producing countries. Due to soil pollution, agricultural productivity in mining areas decreases by **40%** relative to areas farther

TRANSPORT

The number of cars worldwide will nearly **double** by **2040**. Highways are major, open and dynamic sources of contaminants such as heavy metals and toxic organic pollutants that present a risk to adjacent agricultural soils and urban areas



One of the highest ranking problem in Europe

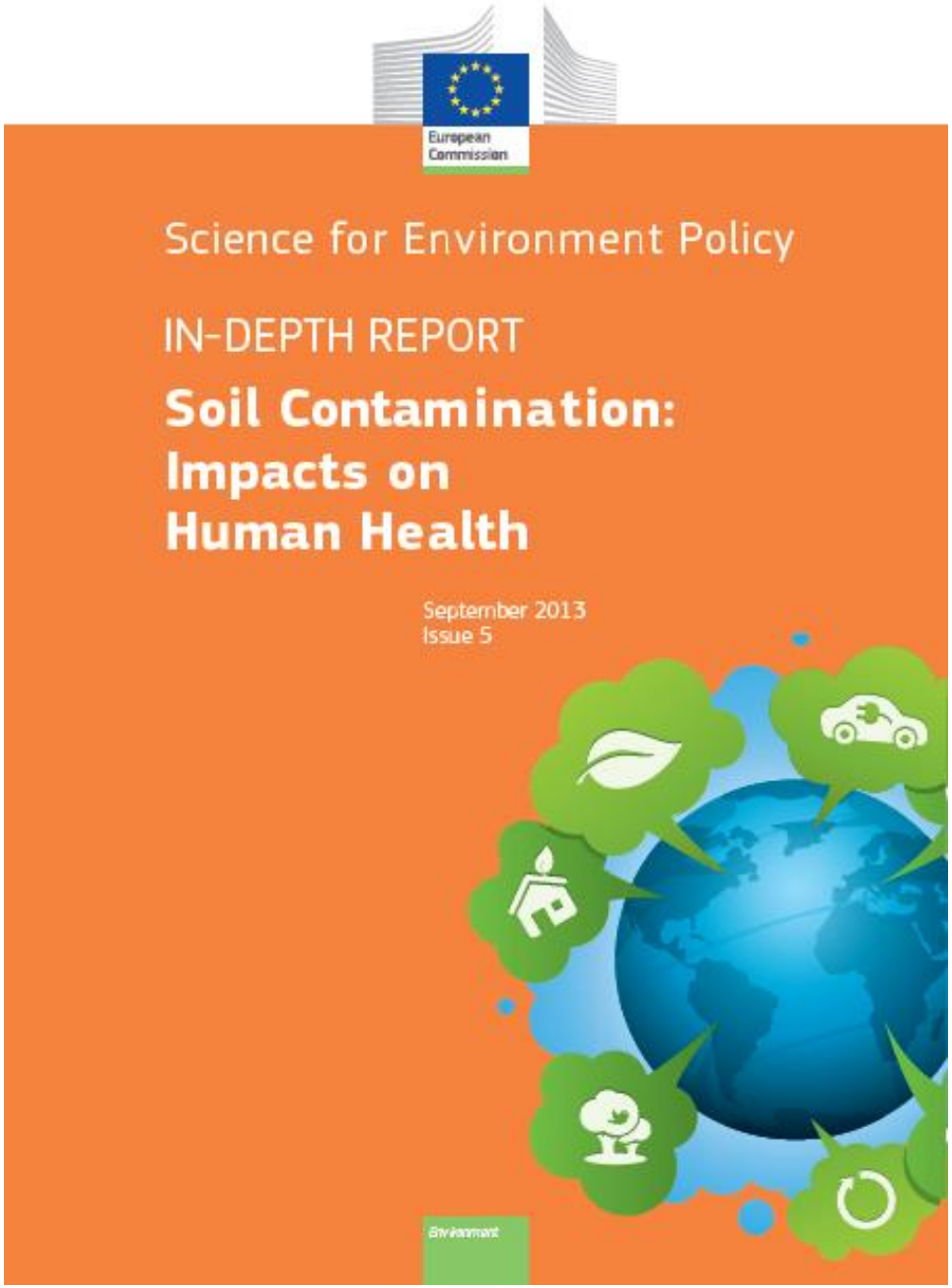


«With a growing population expected to reach 9 billion by 2050, soil pollution is a worldwide problem which reduces food security by either reducing crop yields due to toxic contaminant levels or by producing foods that are unfit for human and animal consumption.
The entity of the problem is still unknown as not certain data are available on a global scale»

Contamination can seriously affect the ability of soil to perform some of its key ecosystems functions, for example it reduces the soil ability to act as a carbon sink, making it difficult to achieve the 1.5/2 °C target of the Paris Agreement (Service de l'observation et des statistiques, 2015)

Soil contamination reduces food security both by reducing yields of crops due to toxic levels of contaminants and by causing the crops that are produced to be unsafe to consume, endangering the possibility of meeting the SDGs (UN, 2017).

2 (zero hunger),
3 (good health and well-being),
15 (life on land)



Decision makers, scientists, businesses and individual citizens generally accept and understand that air and water pollution can have negative impacts on human health, but the impacts of such soil pollution on our health have had a much lower profile, and are not so well understood.

COMMISSION OF THE EUROPEAN COMMUNITIES

Brussels, 22.9.2006
COM(2006)231 final

COMMUNICATION FROM THE COMMISSION TO THE COUNCIL, THE EUROPEAN PARLIAMENT, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS

Thematic Strategy for Soil Protection

[SEC(2006)620]
[SEC(2006)1165]

EN EN

COMMISSION OF THE EUROPEAN COMMUNITIES

Brussels, 22.9.2006
COM(2006) 232 final

2006/0086 (COD)

Proposal for a

DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

establishing a framework for the protection of soil and amending Directive 2004/35/EC

(presented by the Commission)

EN EN

Despite its importance for our society, and unlike air and water, there is no EU legislation specifically targeting the protection of soil

It is important to distinguish between:

- **local soil contamination**

  occurs where intensive industrial activities, inadequate waste disposal, mining, military activities or accidents have introduced excessive amounts of contaminants. Soils only have a limited ability to process these contaminants, through filtering or transformation. Once this ability is exceeded, issues such as water pollution, human contact with polluted soil, plants taking up contaminants and dangers from landfill gases become more significant (*EEA, 2007*).

- **diffuse soil contamination**

  covering large areas

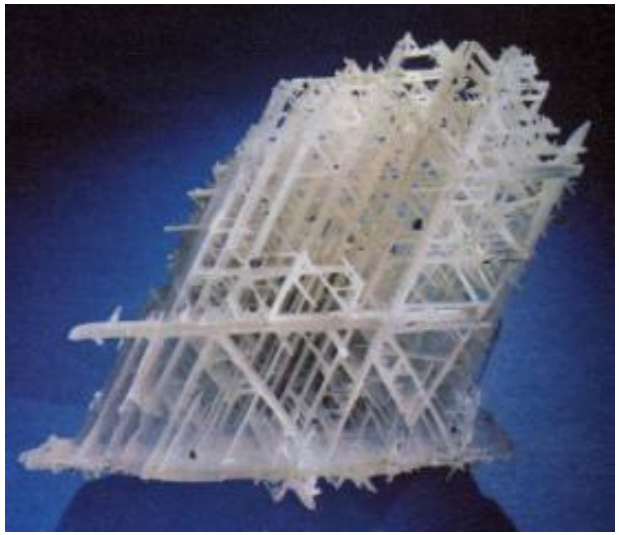
Local contamination

Abandoned mine sites in Morocco

local contamination resulting from past intensive Pb-Zn mining activities (processing and exploitation);

these sites provide sources of contamination by heavy metals which can be transferred by wind and water into nearby soils, stream systems and vegetation.

The most important Pb and Zn mineral-hosts in soil and tailings



Cerussite ($PbCO_3$)

Hemimorphite ($Zn_4Si_2O_7(OH)_2H_2O$)

Smithsonite (ZnCO3)

Soil alkaline conditions (pH 7.9-8.2) and low solubility of Pb and Zn mineral phases

Low mobility by dissolution and low bioavailability of Pb and Zn

the transfer can occur by particles water and wind erosion

given aridity and strong winds, inhalation of airborne particulates may be a concern

P. Iavazzo et al. / Journal of Geochemical Exploration 113 (2012) 56–67

Local contamination resulting from past industrial activities

THE BAGNOLI BROWNFIELD SITE

- In the 1990s abandoned by the Italian steel-producing company *Italsider*
- Classified as Site of National Interest (SNI) (Italian Parliament, 2000)
- Reclamation started in 1994: excavation and soil-washing techniques

Soil morphology strongly disturbed by occurrence and stratification of materials used in the industrial process.

Low mobility of heavy metals

Fine sediments illuviation down the profile

Parco fossili

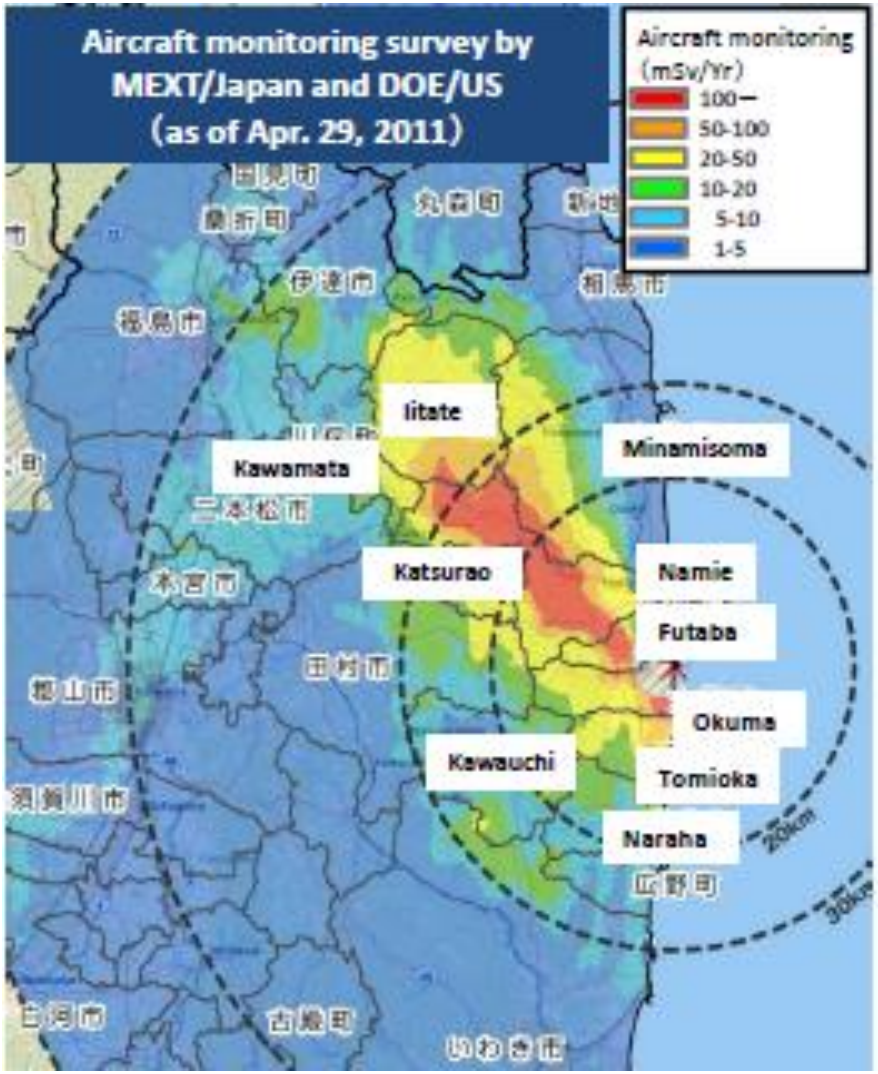
Parco minerali

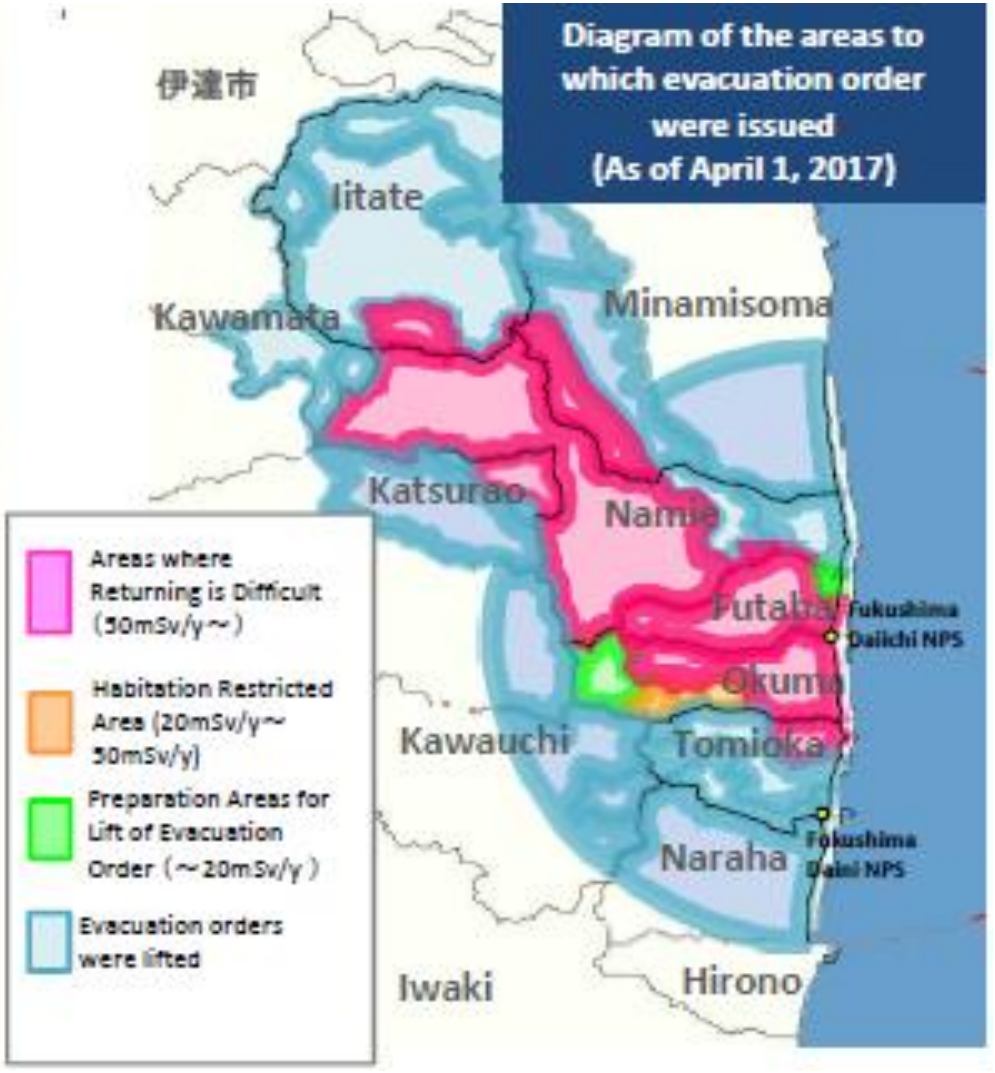
Parco Omo

Campo Americano

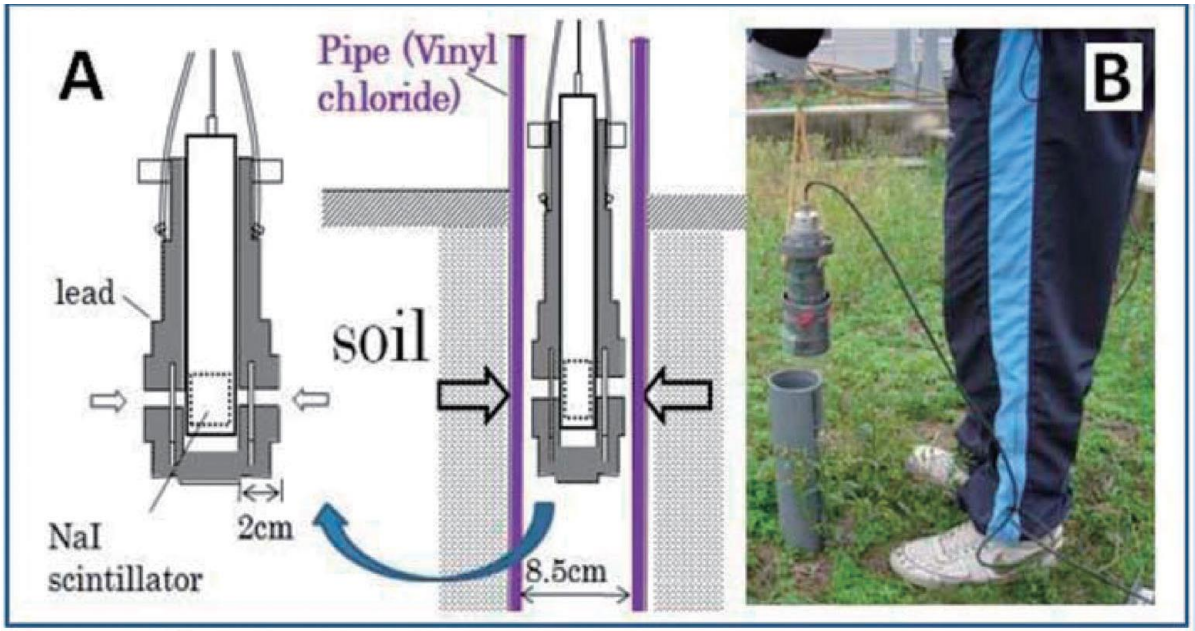
Adamo et al., The Science of the Total Environment 295 (2002) 17–34

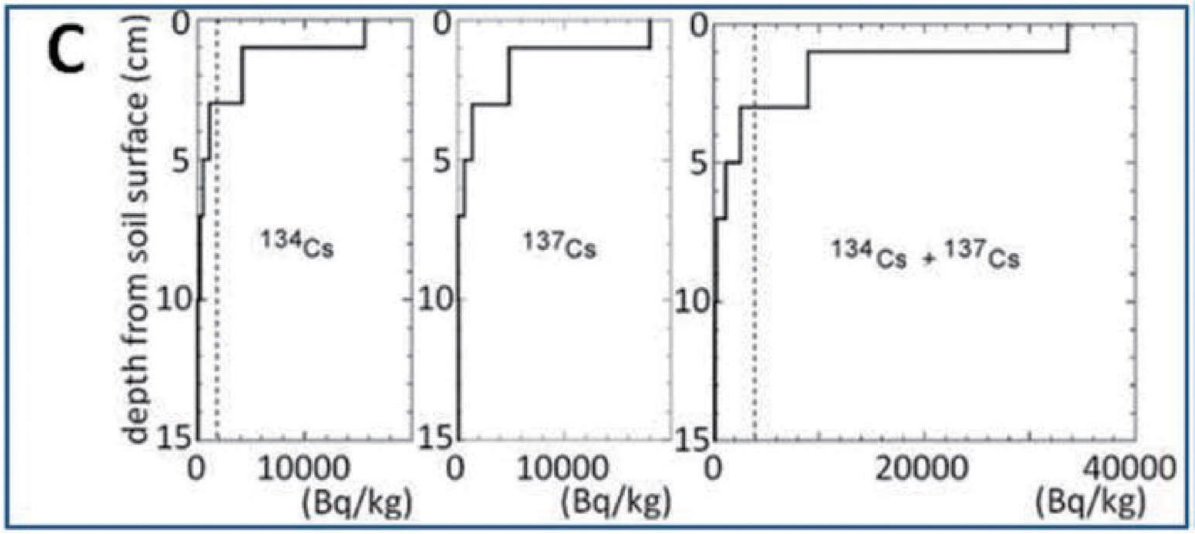
Severe radioactive soil contamination caused by Fukushima nuclear plant accident (FNPA) that occurred following the Great East Japan Earthquake on March 11, 2011.

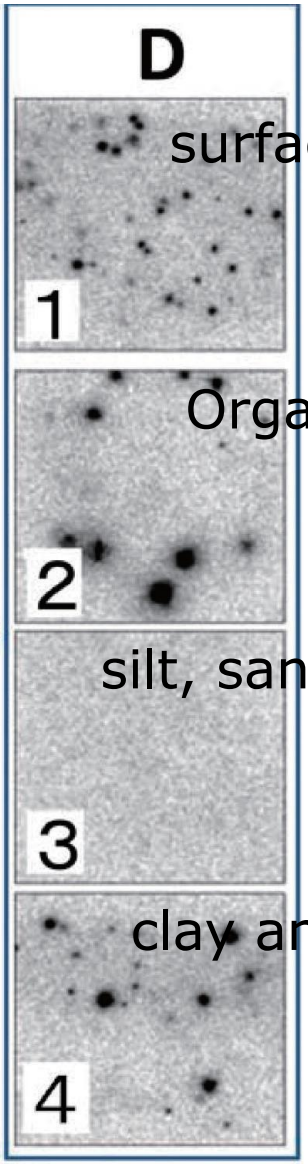




Vertical distribution of ^{134}Cs and ^{137}Cs in the top 0–15 cm layer of soil



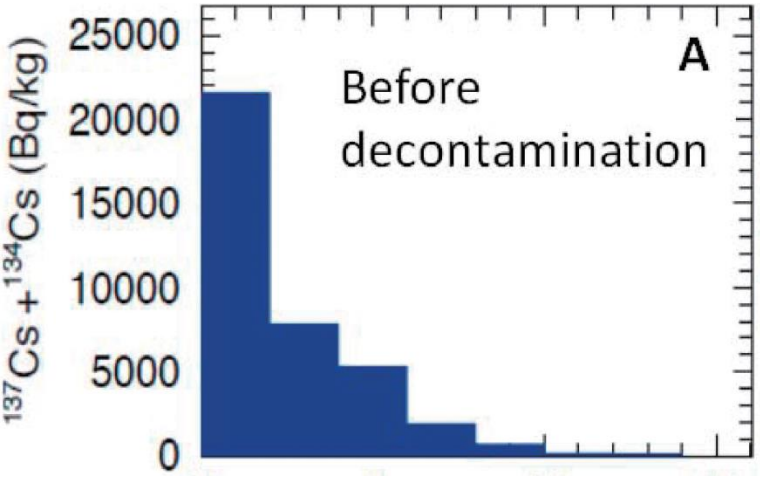


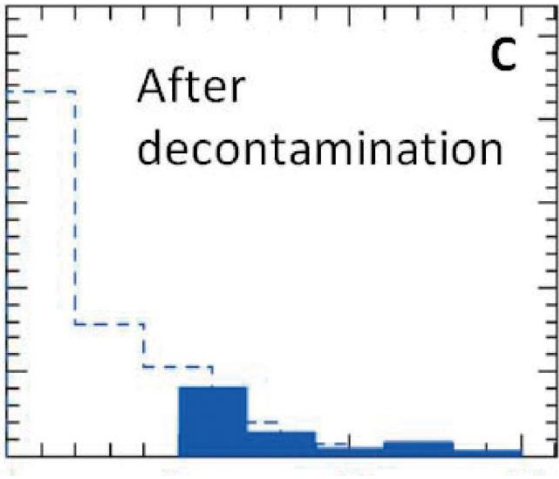


^{137}Cs strongly bound to the fine clay, weathered biotite, and OM in soil (*Nakanishi, 2018*)

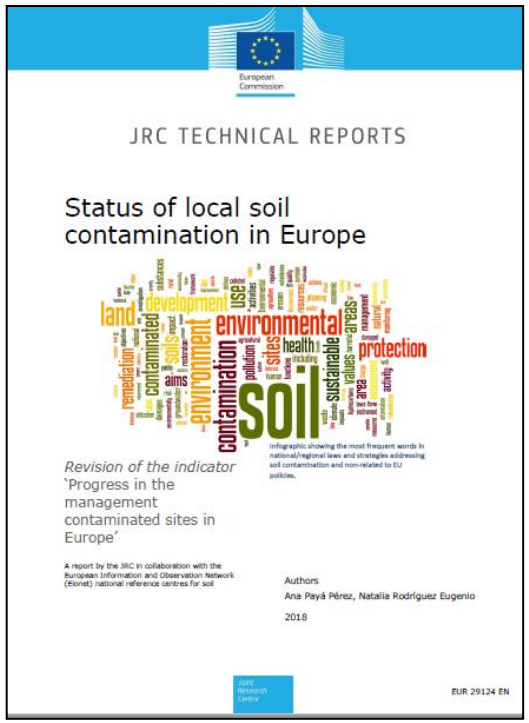
Soil decontamination by Radiocesium

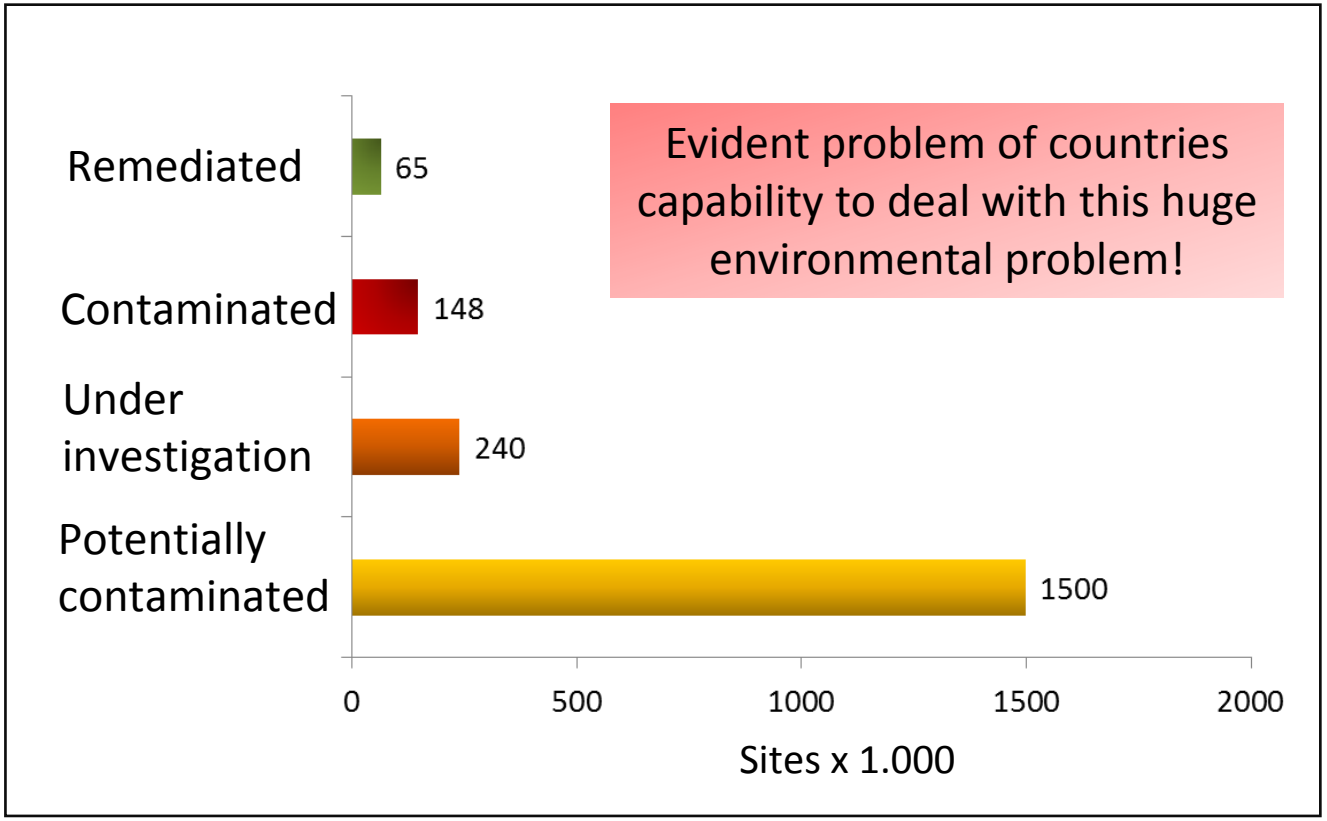
Top soil removing and stripping, soil bags piled up and stored in nuclear plant





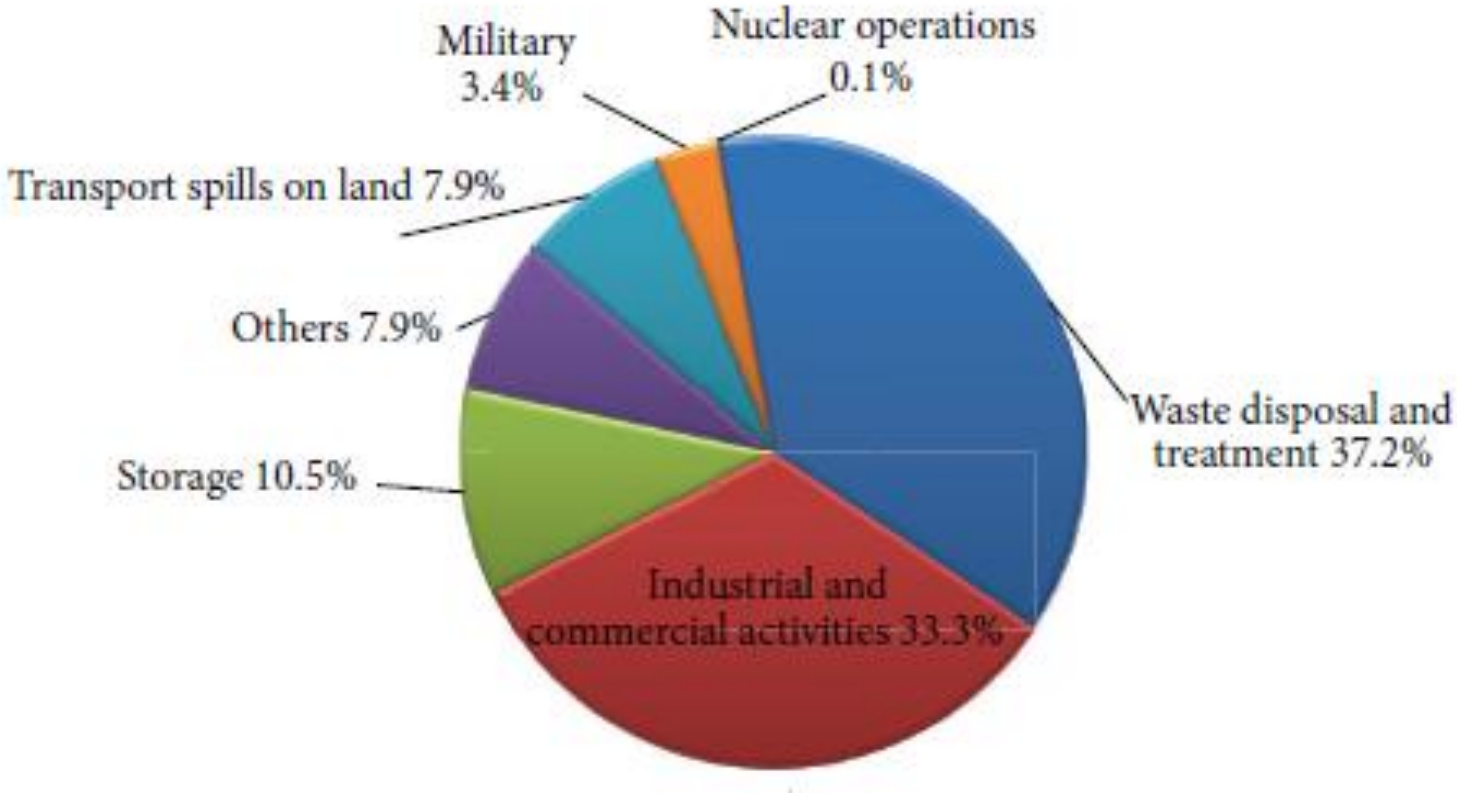
STATUS OF LOCAL SOIL CONTAMINATION IN EUROPE





- in EU around 1,5 millions of **potentially contaminated sites (**19,000 new sites every year)**,** 148,000 (10% PCS) **contaminated sites,** 65,500 (45% CS) **remediated sites (**JRS, 2018)

Overview of activities causing soil contamination in Europe



(JRS, 2014)

Main contaminants affecting soil in and around contaminated sites in EU

Overview of contaminants affecting soil in Europe

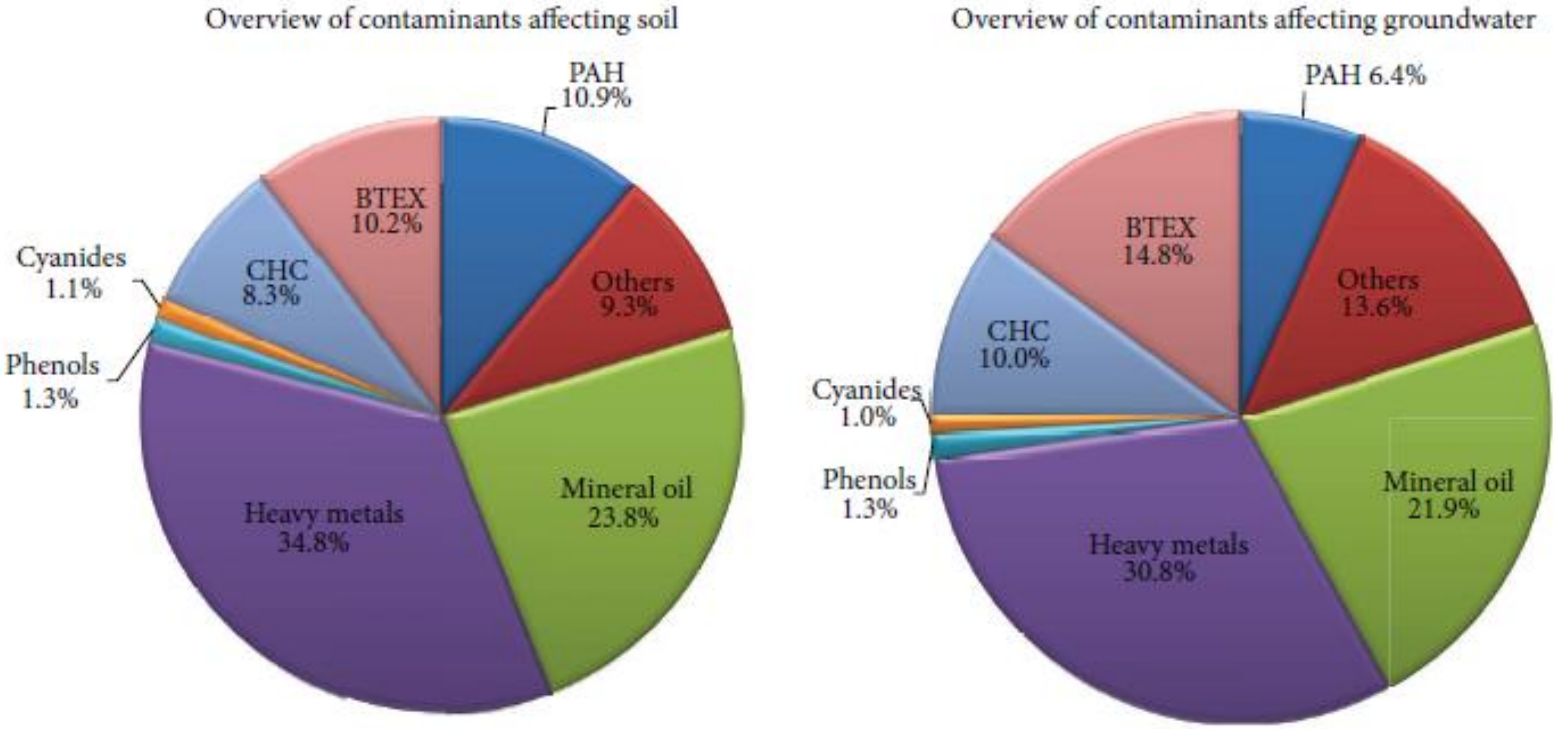
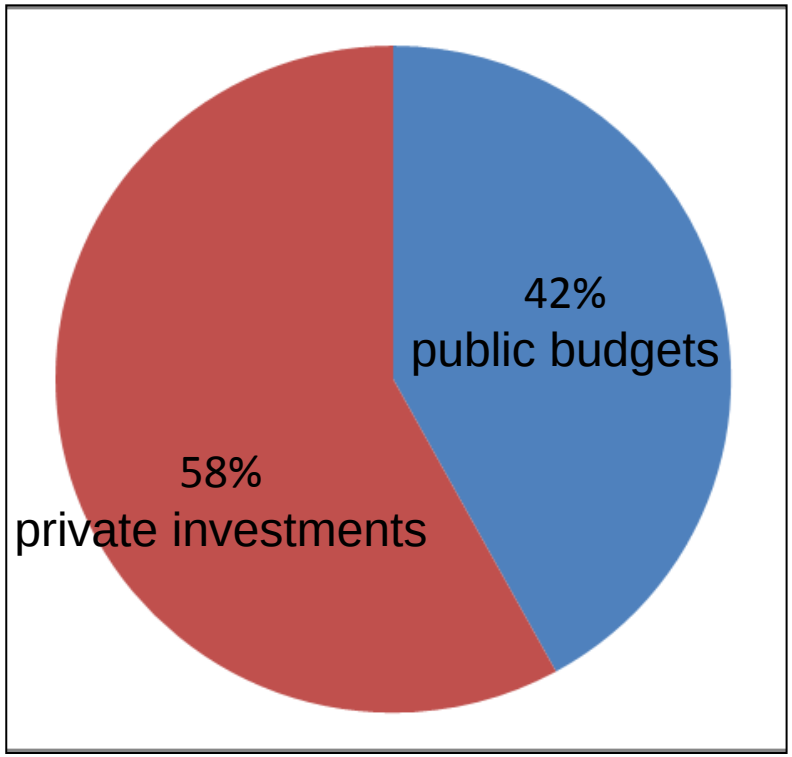


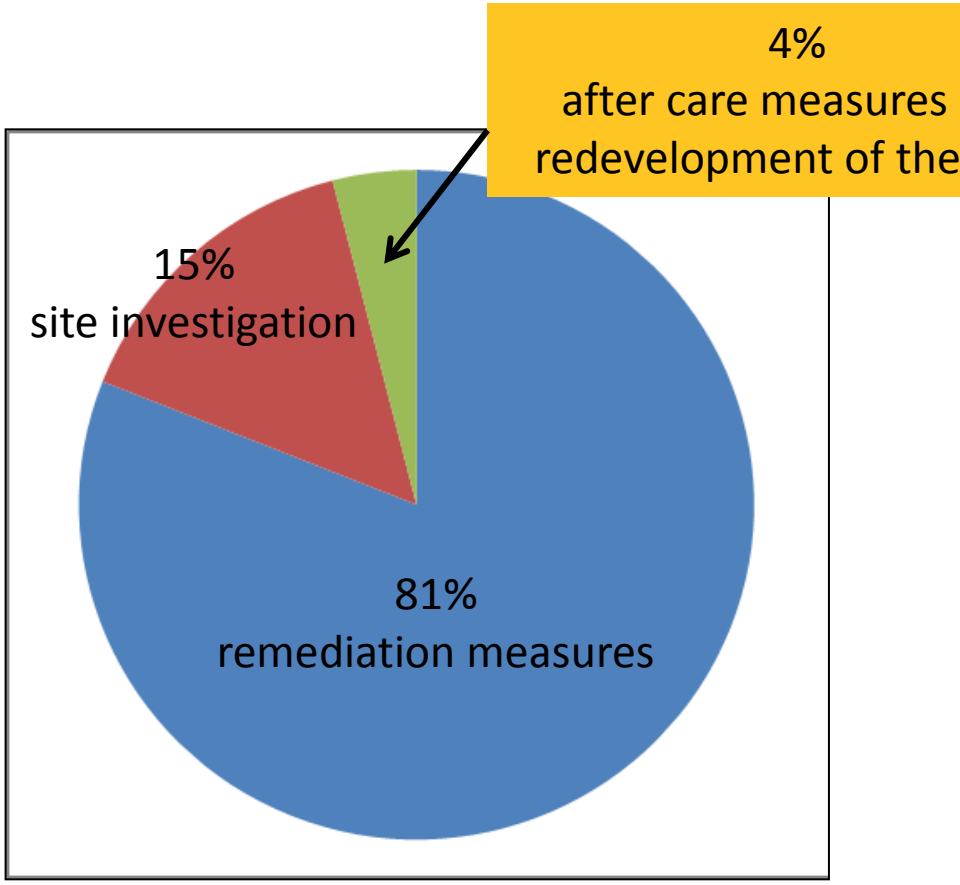
FIGURE 4: Distribution of contaminants affecting soil and groundwater in Europe.

(JRS, 2014)

Annual cost for management of contaminated sites is estimated around 6 billion Euros annually

Very important element taken into account by policy makers and the most criticized issue in the proposed European soil framework directive!





Remediation techniques

The most commonly used remediation procedure seems to be the ex-situ technique “dig-and-dump”, which involves the excavation and off-site disposal of contaminated soil.

Remediation actions are very costly, especially if the area to be remediated is large and the contamination is persistent (European Commission, 2006).

2018 JRS Technical report

When a soil must be considered contaminated?

Table 6. Main approaches and legal documents framing site assessment.

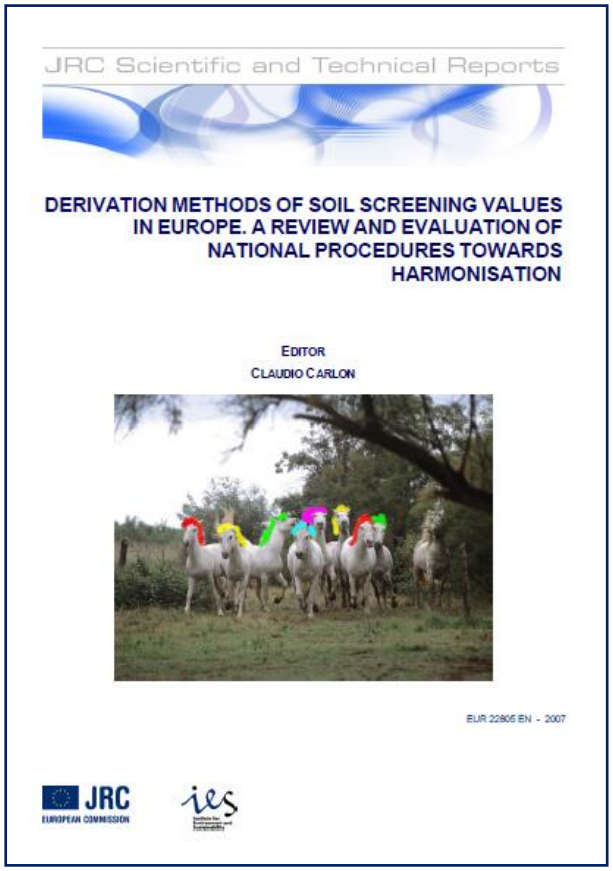
Country	Approach for assessing contaminated sites	Guidance and legal instruments framing site assessment
Austria	Environmental quality standards and site-specific risk assessment.	ALSAG ([58]); water act ([59]); waste-management act ([60]). Austrian Standard ÖNORM S 2088 (part 1: groundwater; part 2: soil; part 3: air) ([61]).
Belgium (Buxelles-Capitale)	For single pollution and mixed pollution: exceeding soil-remediation standards. For orphan pollution: site-specific risk assessment.	Decree on soil remediation and soil management ([62]). S-Risk model.
Belgium (Flanders)	Historical contamination is evaluated using site-specific risk assessment. New contamination is addressed comparing values with soil-quality standards approach.	S-Risk model ([63]).
France	Site-specific risk assessment.	Interpretation of the state of the environments ([70]).
Germany	Risk-based soil screening values (trigger values) and site-specific risk assessment.	Federal soil-protection act ([71]).
Hungary	Site-specific risk assessment to determine remediation limits.	Ministerial decree No 6/2009 (IV. 14.) on the contamination-limit values and measurements necessary for the protection of geological formations and groundwater ([72]).
Ireland	Site-specific risk assessment with a prioritisation in three phases	*Code of practice for environment risk assessment for unregulated waste-disposal sites* ([73]).
Italy	Screening values for assessing the need for investigation and on-site-specific risk assessment for assessing the need for	Legislative Decree n. 152/2006 approving the Code on the Environment ([74]).
Netherlands	Screening values and site-specific risk assessment depending on the tier.	Dutch soil-protection act/soil ministerial circular ([78]). Sanscrit risk-assessment decision tool, including the CSOIL exposure model soil-protection act ([79]).

Combined approaches to encourage staged assessment processes, considering **screening values** but allowing the flexibility to use comprehensive assessment tools for **site-specific risk assessment** are nowadays the most extended practice to deal with soil contamination across Europe.

Screening Values (SVs)

Screening Values (SVs) are generic soil-quality standards defined for most pollutants and different soil uses and adopted in many countries to regulate the management of contaminated soil.

They are in the form of concentration thresholds (mg/kg soil-dw) of contaminants in soil above which certain actions are recommended or enforced.



Soil SVs adopted in EU countries are widely variable for

- terms: screening values, guidance values, target and intervention values, max acceptable concentrations, cut off values, trigger values, environmental quality objectives, etc.

- numerical values

Lack of a coherent framework in Europe for the derivation and in the use of SVs.
Derivation methods have scientific and political bases

SVs for potentially unacceptable risk for metals and metalloids (mg/kg d.w.)(residential soil-use)

	AUT	BE(F)*	BE(B)	BE(W)	CZE	FIN	ITA	LTU	NLD	POL	SVK	UK	DNK
As	50	110	110	300	70	50	20	10	55	22.5	50	20	20
Ba					1000			600	625	285	2000		
Be					20		2	10	30		30		
Cd	10	6	6	30	20	10	2	3	12	5.5	20	2	5
Co					300	100	20	30	240	45	300		
Cr	250		300	520	500	200	150	100	380	170	800	130	1000
Cu	600	400	400	290	600	150	120	100	190	100	500		1000
Hg	10	15	15	56	10	2	1	1.5	10	4	10	8	3
Pb	500	700	700	700	300	200	100	100	530	150	600	450	400
Mo					100			5	200	25	200		
Ni	140	470	470	300	250	100	120	75	210	75	500		30
Sb	5				40	10	10	10	15				
Se							3	5	100		20	35	
Sn					300		1	10	900	40	300		
Te									600				
Tl	10						1		15				
V					450	150	90	150	250		500		
Zn		1000	1000	710	2500	250	150	300	720	325	3000		1000

**For new contaminants only*

Carlon, 2007

Italian screening values (92 contaminants) in soil according to two different land uses (residential and industrial/commercial) - DL 152/2006

		Siti ad uso Verde pubblico, privato e residenziale (mg kg^{-1} espressi come ss)	Siti ad uso Commerciale e Industriale (mg kg^{-1} espressi come ss)
	Composti inorganici		
1	Antimonio	10	30
2	Arsenico	20	50
3	Berillio	2	10
4	Cadmio	2	15
5	Cobalto	20	250
6	Cromo totale	150	800
7	Cromo VI	2	15
8	Mercurio	1	5
9	Nichel	120	500
10	Piombo	100	1000
11	Rame	120	600
12	Selenio	3	15

No SVs for agricultural soils

SVs for assessing the need for investigation (**potentially contaminated soil**)

if available, soil background values are used as reference levels.

on-site-specific risk assessment for assessing the need for intervention (**Contaminated soil**)

Adverse effects are not necessarily only manifested in the environment when PTMs have an anthropogenic origin. Naturally high concentrations of some elements also cause toxicity and lead to natural adaptation of the biota to these high concentrations.

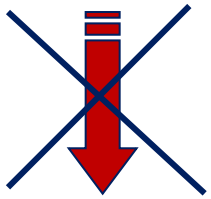
Esempi:

Cr, Ni in serpentine soils (Kelepertzis *et al.*, 2013; Kelepertzis and Stathopoulou, 2013)

As in groundwater in Bangladesh, India, China, Mexico, etc. (Mahimairaja *et al*., 2005)

Se in seleniferous soils (Dhillon and Dhillon, 2003)

Risk management based only on
total or "pseudototal" content of
pollutants in soil might minimize the risks



Mobility, bioavailability,
bioaccessability, biodegradability

Risk/toxicity

Remediation techniques

Management

Where contaminants are tightly bound by the soil and not bioavailable, exhaustive clean-up of soils may be not necessary as the contaminants may not pose a risk to end users. By contrast, the "risk-based land management" (RBLM), may save millions of euros in remediation costs.

- ✓ The pseudototal metal fraction is of little value for the prediction of ecological impact.
- ✓ An increasing need is felt not only to analyse metal concentrations in soils, but also to assess their influence on the terrestrial ecosystem itself, such as toxicity of metals to soil micro-organisms, and on other boundary ecosystems such as ground water, air, plants, animals and humans.

Take home messages

- An evident problem in terms of countries capability to deal with soil pollution problem exists.
- The use of SVs alone might not be appropriate to assess the problem in an efficient and economically viable manner.
- Activities of harmonization of SVs derivation procedures are necessary at a EU level.
- For a correct assessment of risk/toxicity of a polluted soil and to predict its decrease after remediation it is crucial to establish the mobility, bioavailability and bioaccessability of contaminants.
- New approaches moving from measuring concentrations to measuring effects are required.
- A comprehensive EU strategy for soil protection is needed.