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Soil Contamination: Impacts on Human Health

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Soil Contamination: Impacts on Human Health

Contents

This In-depth Report is written and edited by the Science Communication Unit, University of the West of England (UWE), Bristol

Email: sfep.editorial@uwe.ac.uk

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EXECUTIVE SUMMARY

Soil Contamination: Impacts on Human Health

Over 200 years of industrialisation have caused soil contamination to be a widespread problem in Europe. 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.

In the European context, the health impacts of long-term, low-level (or 'chronic') exposure to soil contaminants is of particular interest, and decision makers and researchers have both noted the lack of information in this area. However, the study of soils and human health is a complicated endeavour; singling out a single contaminant to study in isolation does not necessarily offer scientists a true picture of the complex relationships between contaminants, soil and health at work in real life situations.

This In-depth Report from Science for Environment Policy draws on current research and case studies from a number of scientific disciplines that investigate the interaction between contaminated soils and human health. It explains contaminant pathways from soil into the human body and some of the varied properties of soils are also briefly considered; these are an important factor in determining how much of a contaminant is available, both to the human body, and for transport around the surrounding environment.

Taking as a starting point the World Health Organization (WHO)'s ten major chemicals of public health concern, the report includes an overview of some of the most significant sources and known health effects of common contaminants. This is then broken down further into sections which provide detail on individual contaminants, which include case studies illustrating both known health impacts, and areas under investigation.

The most frequent contaminants of soil in Europe are heavy metals and mineral oil, and approximately three million sites are estimated to have been potentially affected by activities that can pollute soil. Of these sites, approximately 250,000 may need urgent remediation. Both of these figures are likely to be underestimates that will rise as data collection methods improve. There is currently no harmonised, pan-European system for collecting data on soil contamination, although some individual countries do have their own systems in place.

Soil contaminants may be responsible for health effects costing millions of euros, but studies to quantify the true cost are in their infancy. Health problems from cancers (arsenic, asbestos, dioxins), to neurological damage and lower IQ (lead, arsenic), kidney disease (lead, mercury, cadmium), and skeletal and bone diseases (lead, fluoride, cadmium) are serious issues, that in many cases we have yet to address.

Heavy metals and persistent organic chemicals are of particular concern. Human activity introduces heavy metals (such as cadmium, arsenic and mercury) to our soils through mining, smelting, industry, agriculture and burning fossil fuels. Our disposal of materials containing heavy metals – a long list which includes paint, electronic waste, and sewage – also contributes to the burden of heavy metal contamination.

Organic chemicals are also part of our industrial legacy, and many are still widely used today. Complex mixtures of these chemicals in the environment and in our bodies pose major challenges to toxicologists trying to understand the health impacts of these widespread substances. There are many methodological challenges relating to the study of soil science, human biology, sampling and the interactions between large numbers of influencing factors on soil and health. Absolute certainty of cause and effect in the more common cases of low level, long-term exposure to a cocktail of chemicals from soil, and other sources, may not be achievable.

We are already beginning to see the longer-term trends and impacts of our industrial heritage and previous activities. Studies on historically contaminated sites shows us that we can never be too careful when taking a decision on where to site modern-day activities, because some contaminants can still be detected at potentially toxic levels decades after they were first released.

A site-by-site approach that takes into account the individual environmental characteristics of soils and human activities is essential: each site has a unique risk profile, a unique chemistry and a unique history. In some cases, a heavy burden of soil contamination can co-exist with a healthy population. But while contamination does not necessarily spell disaster, only research on a case-by-case basis can offer peace of mind.

Introduction

Today, we all acknowledge the significance of pollutants in the air or in water contributing to poor health. Measures of air quality are often reported along with our daily weather, and the impacts of a lack of access to safe drinking water, or of industry discharging pollution into rivers and lakes, are well documented. In many cases, clear links have been drawn between the types and levels of specific contaminants in the air or water, and their health effects.

However, until recently, the impacts of soil pollution on our health have had a much lower profile. In addition, the science involved is complex (Science for Environment Policy, 2012). Researchers are making good progress with developing our understanding of many soil-related issues, such as soil sealing, erosion and contamination, but the impacts of soil contamination on our health are not as well documented. This report aims to begin filling this gap in information for decision makers, with a particular focus on offering explanations of the scientific issues around how soils behave, details of common contaminants in our soils, and what we know about the potential risks to health from soil contamination.

In a European context, one topic of particular concern is citizens' long-term, low-level exposure to a range of soil contaminants, including both current and legacy (historical) emissions. Cases of populations suffering from high levels of soil contamination in specific locations around the world have been studied extensively by epidemiologists and toxicologists to understand the health impacts of soil-borne chemicals in the environment. In these cases, the cause and effect are often relatively straightforward to determine. However, the effects of living for many years on or near soils with above-average levels of contamination can be harder to determine. The study of soils and human health is a complicated endeavour: traditional scientific approaches that isolate a single variable, such as a specific contaminant, and then investigate that variable are not effective in this case, because many of the issues that affect human health involve complicated and synergistic relationships (Brevik *et al*, 2013).

This report focuses primarily on soil contaminants from human activity, for example, from industrial processes, mining, household/business waste, human and animal pharmaceuticals. It provides an overview of current research and presents case studies concerning heavy metals and synthetic organic chemicals. Soil also contains a great number of biological contaminants (e.g. pathogens, such as tetanus, and parasites, such as hookworm), which cause many well-documented impacts on human health. However, these will not be covered in this report.

Those studying the interactions between soil science and human health come from many academic disciplines, including chemistry, geology, geography, anthropology, biology, agronomy, sociology, public health and medicine. As a result, to achieve a clear overview of how soil contamination affects our health requires interdisciplinary teams, and good communication between researchers from different fields. In addition to the scientific challenges, fostering successful interdisciplinary collaboration is also important if we are to fill the gaps in our knowledge of how the state of the soil interacts with human health.

1.1 Context: soils in Europe

Many case studies from heavily-contaminated sites around the world, particularly (but by no means exclusively) in developing countries, indicate the possible health impacts of high levels of soil contamination. These offer useful data that may help us to understand the medical outcomes of ingesting these chemicals. However, they do not necessarily predict the specific health outcomes in a European context.

The soil resources of Europe are diverse. Relatively young soils dominate northern and central Europe, and soils in northern Europe tend to have higher organic matter content than those in the south. Poorly developed soils or soil with accumulations of calcium carbonate characterise the Mediterranean basin. The European Soil Data Centre (ESDAC), managed by the EU's Joint Research Centre (JRC), is a focal point for pan-European data on soil. According to a recent report by the JRC, *'our knowledge base on many of the key functions of soil that deliver vital environmental services and goods is still poorly developed.'* (European Commission, 2012).

Despite its importance for our society, and unlike air and water, there is no EU legislation specifically targeting the protection of soil, although various policies regarding water, waste, chemicals, industrial pollution, nature protection, pesticides and agriculture all contribute to soil protection. For this reason, the European Commission has adopted the Soil Thematic Strategy (Commission Communication COM (2006) 231) and proposals for a Soil Framework Directive (Commission Proposal COM (2006) 232) specifically to protect soils. Among the goals of these instruments, of particular relevance to this report, is the protection of soils from a number of threats, including contamination.

Following over 200 years of industrialisation, soil contamination is a widespread problem in Europe. The most frequent contaminants are heavy metals and mineral oil. According to estimates by the European Environment Agency (EEA, 2007), the number of sites where potential polluting activities have been carried out in the EU is approximately three million and, of these, an estimated 250,000 sites may need urgent remediation. The main causes of contamination are past and present industrial and commercial activities, and the disposal and treatment of waste, but these categories vary widely across Europe.

One issue that increases the challenge of assessing the state of soils across Europe is that there is currently no legal requirement to collect information in a harmonised manner, if at all. Many European countries have mapped soils used for agriculture or forestry, but this data may be several decades old. This is an important consideration when discussing the potential impacts (including health impacts) of pollutants on soil.

Some countries do have detailed soil monitoring networks to measure soil quality, however, these may reflect national or regional priorities and standards, so comparing results between countries is difficult. Other nations do not have systems in place for systematic soil data collection. Recent improvements in data collection mean that the number of reported contaminated sites could increase by as much as 50% by 2025 (EEA, 2007).

Two different types of soil contamination to consider are local soil contamination (the result of intensive industrial activities or waste disposal) and diffuse soil contamination covering large areas. This report will mainly focus on local soil contamination. Pollution by heavy metals and organic contaminants is probably the most serious problem as the contamination is practically irreversible. Contamination can affect human health either through direct contact or by ingestion through the food chain. While many of the relationships between soil and health are unclear and require further research, according to the JRC's *State of the Soil in Europe* report, the following sections of the report look at some of the current information we do have about soils and health.

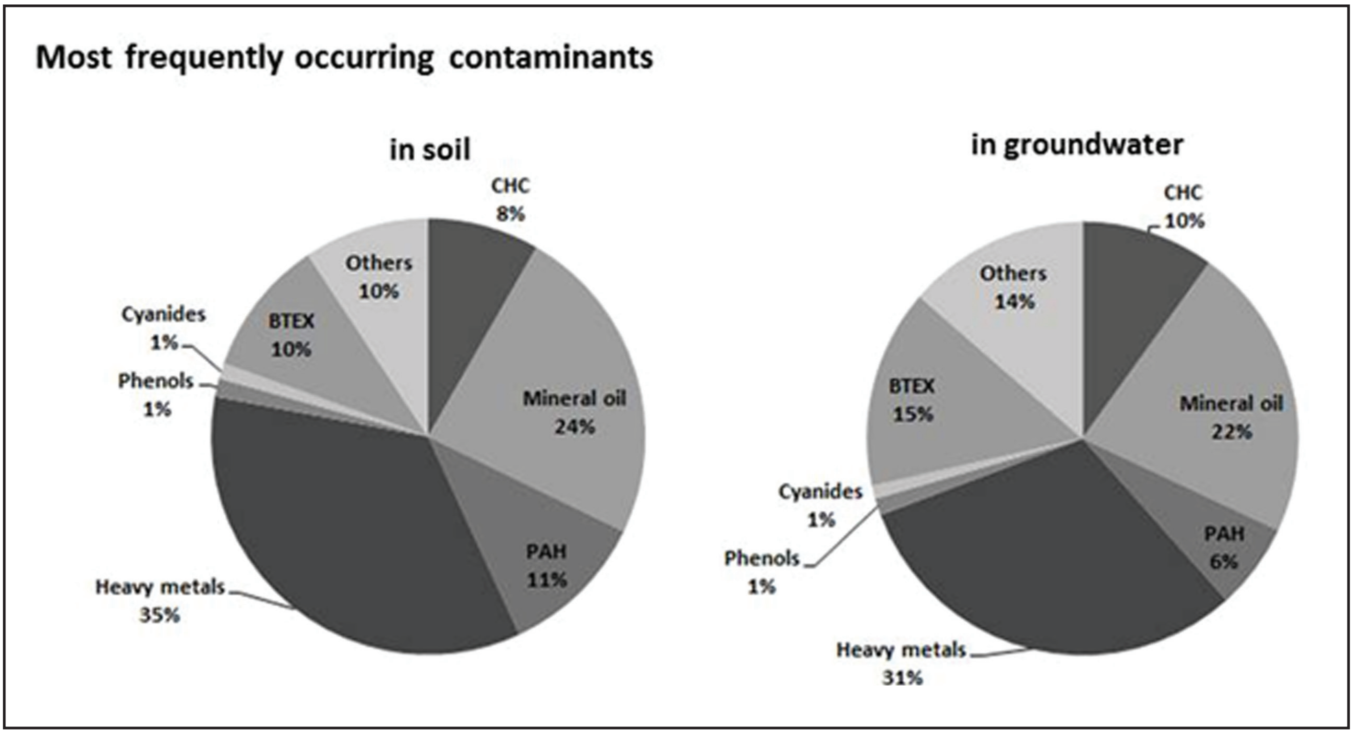

Figure 1: The results of a questionnaire compiled recently by the JRC are shown above. The questionnaire was sent to 39 European countries; 27 countries returned the questionnaire. Source: Huber & Prokop (2012).

2. Key concepts in understanding soil contamination and health

2.1 Soil properties

Soils vary considerably in their composition across Europe. This is significant to human health, because parent material (the weathered rock materials from which soils are formed), topography, climate, organisms and time will lead to soils with different physical and chemical properties. A soil's unique composition will affect how much water it can hold, the living organisms it supports, which chemical reactions are likely to occur, and how it cycles nutrients. All of these factors will determine what happens to potentially harmful contaminants in soils, how they may be transported or transformed, and the extent to which they may be available in chemical forms that are harmful to human health.

Soil pH (acidity) is of particular importance because it controls the behaviour of metals and many other soil processes. Heavy metal cations (positively charged metal atoms) are most mobile in acid soils. This means that metal contaminants are more available for uptake by plants, or to move into the water supply. Making soil less acidic, by adding lime, is one way to reduce the bioavailability of metals (Oliver, 1997).

2.1.1 Classifying soils

A number of different systems for classifying soils exist, and a number of countries around the world, including Australia, Brazil, France, Canada, New Zealand and the United States, each have their own system. The United Nations Food and Agriculture Organization (FAO) and UNESCO began to develop a system for soil classification in 1980 that has since evolved through wide consultation to become the World Reference Base (WRB) for Soil Resources[1].

2.1.2 Soil health

Farmers often use the term 'soil health', which is similar to the term 'soil quality' used by soil scientists. A healthy soil has several physical, chemical and biological properties: it needs to incorporate adequate organic matter, have a good structure, and be home to a diverse mix of organisms. These properties allow the soil to carry out important functions, and may be achieved in a natural setting by a soil reaching equilibrium with its surroundings, or in managed settings by human intervention to improve the soil's health. Agricultural soil health is linked to human health, as poor soils yield fewer crops with decreased nutritional value. Healthy soils also limit erosion, and help improve air and water quality (Brevik *et al*, 2013).

Contamination can seriously affect soil's ability to perform some of its key functions in the ecosystem. Soil is a living resource, but once contamination exceeds a certain threshold, the soil may be considered 'functionally dead'. Pollution by heavy metals and many organic contaminants is practically irreversible (European Commission, 2012).

2.2 Causes of soil pollution

The European Commission has proposed the following definition of 'contaminated site': a site where there is a confirmed presence, caused by human activities, of hazardous substances to such a degree that they pose a significant risk to human health or the environment, taking into account land use (Commission Proposal COM (2006) 232).

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, for example. 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).

The report of the Technical Working Group on soil contamination (Van Camp *et al*, 2004), established in preparation of the European Commission's Thematic Strategy for Soil Protection, provides a comprehensive summary of the sources and distribution of contaminated soils in Europe.

Some key points relevant to impacts of soil contamination on health mentioned in Van Camp *et al*'s report are:

- In most cases, soil pollution from point sources is unintended and happens due to handling spills or accidents or insignificant but continual losses/emissions.
- Consumer behaviour and the industrial sector are contributing to the increase in the number of potential sources of contamination, such as municipal waste disposal, energy production and transport, mainly in urban areas.
- In Central and Eastern Europe, many problems stem from past activities and poor management practices. Here, soil contamination is, to a great extent, a result of the legacy of inefficient technologies and uncontrolled emissions. Problem areas include some 3,000 former military sites, abandoned industrial facilities and storage sites which may still be releasing pollutants to the environment (Andersen, 2000). One of the major impacts is groundwater contamination and related health problems.
- Monitoring is specific to each individual site and is not very representative of other locations, unless there are a larger number of similar sites. Reporting is only relevant at an EU level for very large sites ('megasites'), where risk management plans are at the regional scale. Examples of megasites include The Kempen, in the Netherlands and Belgium; the old coal and steel region in the North of France; and the Bitterfeld area in Germany.
- Data on concentrations of contaminants at individual sites are not necessarily relevant for EU policy discussions.
- The soil's capacity and resilience in terms of holding onto and transforming contaminants mean that damage is not perceived until it is far advanced.

[1] *See: http://www.fao.org/nr/land/soils/soil/en/*

2.3 Routes from soils to human intake

Soil can enter our bodies via three main routes: eating, inhalation and through the skin.

Eating soil (geophagia) is a surprisingly widespread practice. Children under three, in particular, are very likely to eat soil while playing outdoors. As they are considered particularly sensitive to contaminants, young children are thought to be at highest risk from contaminated soils (for example, children absorb lead via their digestive system five times more efficiently than adults). Accidental ingestion may occur in adults (for example, by eating vegetables with some soil still attached), but in some parts of the world, adults also deliberately eat soil for a number of cultural reasons. It is commonly believed that direct ingestion is the most important pathway for human exposure to soil contamination, although other specific pathways have some importance in certain situations.

When consumed, some chemicals are absorbed through the lining of the mouth, while others are swallowed and move into the digestive system. From here, they may be absorbed into the body and transported to the liver.

Once in the liver, some chemicals are largely returned to the digestive system via bile, but others will enter the bloodstream. Some chemicals are broken down to a certain extent in the liver before they reach the blood. Where chemicals are not absorbed, and remain in the gut, they generally do not cause an adverse response, unless they have some direct toxicity to the gut lining.

Inhalation Working with soil (for example, in agriculture) releases particles into the air that may be inhaled by workers and others nearby. Very small particles may lodge in the lungs, and there is a chance that contaminants may be absorbed into the bloodstream[2]. Compared to ingestion, this is a far less significant source of exposure, but may be relevant to those exposed repeatedly over a long time period.

Skin contact Absorption through the skin tends to favour more volatile, organic compounds. This is less of a problem for heavy metals, although some specific forms (Cr(VI), the more toxic form of chromium, or inorganic mercury) can cause skin contact problems. Absorption of a chemical through the skin is known as 'dermal absorption', or sometimes 'cutaneous' or 'transcutaneous absorption'.

Indirect contact Soil contaminants may move from soils into ground or surface water, leading to contaminated drinking water. They may also be taken up by plants which are subsequently consumed, either by humans or by agricultural livestock, causing contaminants to enter the human food chain. Some of these effects may be quite significant, as in the case of dioxins accumulating up the food chain, or large quantities of cadmium in crops grown in contaminated soils. High levels of arsenic in drinking water supplies are often another significant indirect result of soil contamination. Arsenic may also be naturally present in groundwater.

A contaminant becomes toxic in the human body once the body's own detoxification systems become overloaded. At this point, the body starts to be exposed to excess amounts either of the chemical itself or of a metabolite produced when the body's normal metabolic pathways (the means of processing the toxic compound) are saturated.

If a chemical accumulates in tissues, reaching critical toxicity may be an event that results from long-term accumulation. Factors that are relevant in this case are the body's rate of elimination (by metabolism or excretion), and the overall 'body burden' – the quantity of chemicals stored in body tissues (Environment Agency, 2009). Reliable data from human populations exposed to known levels of chemicals are not common, with the exception of human pharmaceuticals. For the majority of chemical contaminants, levels likely to pose risks to human health are estimated from toxicology studies on laboratory animals, and models.

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[2] *In 2003, Margot Wallström, European Commissioner for Environment, submitted a sample of her blood for testing as part of a bio-monitoring survey conducted by the World Wildlife Fund (WWF). The Department of Environmental Sciences of Lancaster University, UK, checked for 77 manmade chemicals, which can be found in everyday products, such as television sets, carpets, furniture and food. The 77 chemicals fall into three groups: PBDEs (Poly Brominated Diphenyl Ethers), PCBs (Poly Chlorinated Biphenyls) and OCPs (OrganoChlorine Pesticides). Of the 77 chemicals analysed, 28 were present in Mrs Wallström's blood. See: http://europa.eu/rapid/press-release_MEMO-03-219_en.htm*

3. Types of contamination

As a starting point for looking at the types of contaminant that could be present in soils and affect human health, it is worthwhile to consider the chemicals that offer the greatest threat to human health first. The grid below gives details on the chemicals of major public health concern identified by the WHO (see Figure 2 and Table 1). Chemicals relating to soil and their known health effects (drawn from sources referenced by this report and collated by this report's author) are highlighted in this table. It should be noted that some of the known health effects from these chemicals are based on cases where sources other than soil were the cause (e.g. drinking polluted water).

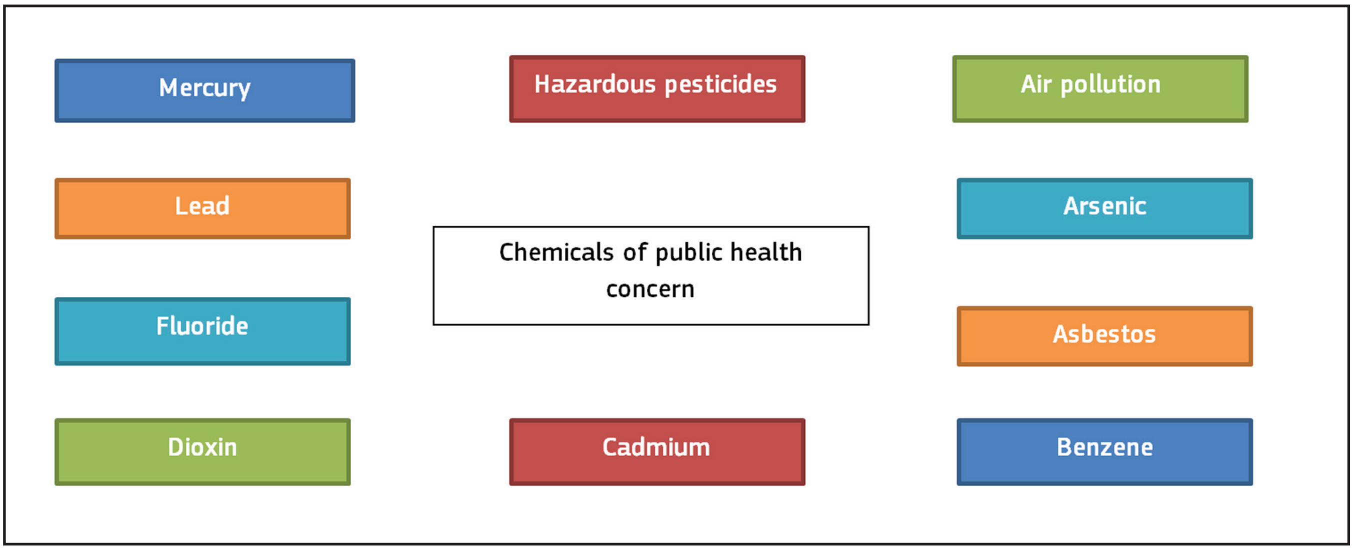

Figure 2: Ten chemicals of major public health concern. Source: adapted from WHO[3]

3.1 Heavy metals

'Heavy metals' is a widely-used term for elements with metallic properties - it is not, in fact, a scientifically accurate description, since the definition of 'heavy' is not fixed, and some so-called heavy metals, such as arsenic and antimony, are semi-metals or metalloids. Another description often used interchangeably with heavy metals is 'trace elements'. These elements occur naturally in rocks and in variable amounts in soils, depending on their location and the rocks that have broken down to make the soil's components. The group 'heavy metals' for the purpose of discussing health risks or impacts generally includes:

- Arsenic (As)
- Lead (Pb)
- Cadmium (Cd)
- Chromium (Cr) (although only the form Cr(VI) is toxic)
- Copper (Cu)
- Mercury (Hg)
- Nickel (Ni)
- Zinc (Zn)

Several of these elements are necessary for human health, and are beneficial when taken in to the body in foods or as supplements at appropriate, low levels. Conversely, cadmium, lead and mercury have no known biological function and are toxic to humans.

Soil acts as a repository for many heavy metals that human activity releases into the environment. This may protect the wider environment to some extent by 'locking away' heavy metals and preventing them reaching other parts of the environment, such as water supplies. However, the soil itself may then present a risk to those who live or eat crops grown on it (Morgan, 2013).

Some soils have naturally high levels of heavy metals and, in some cases, plant species able to take up and store large amounts of heavy metals have evolved in these locations. Human activity such as mining, smelting, industry, agriculture and burning fossil fuels all contribute to the burden of heavy metals in soils, as does our disposal of materials containing heavy metals, a long list which includes municipal waste, paint, electronic waste, and sewage.

Our understanding of how heavy metals in soils lead to human health risks is limited, compared to our knowledge of impacts via air or water. This report focuses on evidence relating to health impacts for the four heavy metals identified in the WHO 'ten leading chemicals of concern' list: arsenic, cadmium, lead and mercury.

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3. See: http://www.who.int/ipcs/assessment/public_health/chemicals_phc/en/index.html

Chemical of concern, Sources/uses	**In soil?**	**Used by humans as a nutrient?**	**Toxic to humans how?**	**Health effects**
Air Pollution	**No**			
Arsenic Pesticides; gold, lead, copper, nickel, iron and steel mining and/or processing; coal burning; wood preservatives. Pharmaceutical and glass industries, sheep dip, leather preservatives, pigments, poison bait, agrochemicals, antifouling paint electronics industry.	**Yes**	**No**	Main exposure through consumption of groundwater containing naturally high levels of inorganic arsenic, food prepared with this water, or food crops irrigated with water high in arsenic.	Intake of inorganic arsenic over a long period can lead to chronic arsenic poisoning (arsenicosis). Gastrointestinal tract, skin, heart, liver and neurological damage. Diabetes. Bone marrow and blood diseases. Cardiovascular disease. Carcinogenic. Organic arsenic compounds are less harmful to health, and are rapidly eliminated by the body. Increased risk of miscarriage, stillbirth and pre-term birth.
Asbestos Mining and milling of raw asbestos (historical) for construction and product manufacture. Historical: releases into the air and soil around refineries, power plants, factories handling asbestos, shipyards, steel mills, vermiculite mines, and building demolitions. Current: repair, renovation, removal, or maintenance of asbestos. Gardening.	**Yes**	**No**	Exposure occurs when asbestos-containing material is crumbling or disturbed, releasing microscopic asbestos fibres into the air and dust. The main route of entry is inhalation, but it can also be ingested or lodge in the skin.	Some inhaled asbestos fibres reach the lungs, where they become lodged in lung tissue and may remain for many years. This causes: • parenchymal asbestosis • asbestos-related pleural abnormalities • lung carcinoma • pleural mesothelioma Health effects may not emerge for decades, but lung cancer and pleural mesothelioma have high mortality rates. Historical, occupational exposure from manufacturing and construction work is a common cause.
Benzene	**No** Benzene is not persistent in surface water or soil, either volatilising back to air or being degraded by bacteria (unless present in very high quantities).	**No**		
Cadmium Zinc smelting, mine tailings, burning coal or garbage containing cadmium, rechargeable batteries (nickel-cadmium batteries account for over four-fifths of cadmium consumption), pigments, TVs, solar cells, steel, phosphate fertiliser, metal plating, water pipes, sewage sludge.	**Yes** Cadmium in soil may enter plant crops (depending on soil characteristics, pH etc).	**No**	Cadmium in soil or water used for irrigation can lead to accumulation in plants that enter the human food chain. Cadmium may also accumulate in animals at levels that do not affect the animal's health, but can affect humans consuming animal products.	Liver and kidney damage, low bone density. These symptoms are known as itai-itai disease. First identified when cadmium from mining in the Toyoma Prefecture of Japan led to high levels of cadmium in rice, which accumulated in local people. Diets poor in iron and zinc vastly increase the negative health effects of cadmium. Carcinogenic (by inhalation).
Dioxin Including Polychlorinated dibenzodioxins (PCDD) and Polychlorinated dibenzofurans (PCDF). Waste incineration, reprocessing metal industry, paper and pulp industry, contaminated herbicides (a major source). Stored PCB-based industrial waste oils (often with large amounts of PCDFs).	**Yes** These chemicals are most commonly found in soils, sediments and food, with low levels in air and water.	**No**	Human exposure to dioxin and dioxin-like substances occurs mainly through consumption of contaminated food. More than 90% of human exposure is through food, mainly meat and dairy products, fish and shellfish.	Dioxins are highly toxic and can cause reproductive and developmental problems, damage the immune system, interfere with hormones and also cause cancer.
Fluoride	**Yes** – but is generally immobile.	**Yes** A micronutrient: Appropriate levels strengthen teeth.	Usually associated with high levels of fluoride in drinking water.	Skeletal fluorosis: fluoride accumulates progressively in the bone over many years. Early symptoms include stiffness and pain in the joints. Crippling skeletal fluorosis is associated with osteosclerosis, calcification of tendons and ligaments, and bone deformities.
Lead Batteries, solder, ammunition, pigments, paint, ceramic glaze, hair colour, fishing equipment, leaded gasoline (vehicle exhausts), mining, plumbing, coal burning, water pipes.	**Yes**	**No**	Leaded fuel and mining activities are common causes for elevated lead levels in topsoil.	• Neurological damage • Lowers IQ and attention • Hand-eye co-ordination impaired • Encephalopathy • Bone deterioration • Hypertension • Kidney disease
Mercury Electrical switches, fluorescent light bulbs, lamps, batteries, thermometers, dental fillings, mining (particularly artisanal/small scale gold mining), pesticides, medical waste, burning coal and fuel oil, chlor-alkali industry.	**Yes**	**No**	Main exposure route for the population at large is via eating contaminated seafood. For children is direct ingestion of soil.	• Central nervous system (CNS) and gastric system damage • Affects brain development, resulting in a lower IQ • Affects co-ordination, eyesight and sense of touch • Liver, heart and kidney damage. • Teratogenic
Hazardous pesticides Herbicides derived from trinitrotoluene may have the impurity dioxin, which is highly toxic. Synthetic insecticides, such as DDT (now banned) can still be found in the environment worldwide.	**Yes**	**No**	Organic pesticides accumulate in the food chain.	Organic chemicals, including pesticides, have been linked to a wide range of health problems, but we tend to be exposed to a cocktail of these chemicals at low levels. Conclusive proof of cause and effect in humans is challenging.

Table 1: WHO ten chemicals of major public health concern in relation to soils and human health impacts. Sources: Brevik & Burgess (2013) and US Agency for Toxic Substances & Disease Registry (website): www.atsdr.cdc.gov

Box 1. Where are the heavy metal hotspots in Europe?

Research published in 2008 aimed to map the concentrations of eight critical heavy metals in Europe (arsenic, cadmium, copper, mercury, nickel, lead and zinc). High concentrations of cadmium, copper, mercury, lead and zinc can be linked with human activities, i.e. industrialisation and intensive agriculture.

The researchers also found a correlation between higher levels of nickel and chromium and the magnitude of earthquakes. (Earthquakes are related to specific geological features and plate boundaries.)

Source: Rodriguez Lado, Hengl & Reuter (2008)

Case Study 1. Heavy metal dispersal from abandoned Spanish mines

Researchers have shown how heavy metals present in tailings from the Cabezo Rajao abandoned mining area in south-east Spain are transported by surface runoff and strong winds. The mine is very close to the protected environmental area, the Mar Menor Coastal Lagoon.

The metals' dispersion patterns vary depending on their solubility and mobility in the aquatic environment and the rainy season is a key time period when the metals are dispersed by water over an extensive area, affecting agricultural fields and urban soils, as well as water bodies and streams.

The area surrounding the mine is rich in carbonates, which are naturally alkaline. This alkalinity plays an important role in metal stability by balancing the pH of the acidic mine tailings and allowing more of the metals to be bound to soils and sediments, with fewer in soluble form. This means that there is no transfer of soluble heavy metals to the protected lagoon.

The study gives an example of how the local climate and geology are relevant to metals' spread in the local area: the semi-arid climate, heavy rains for a short duration and the presence of a high proportion of carbonates all combine to give a unique profile for the presence and availability of heavy metals in soils around Cabezo Rajao (Navarro *et al*, 2008).

3.1.1 Arsenic

Arsenic is found throughout the Earth's crust, generally in the form of arsenic sulfide, or metal arsenates and arsenides. Key industrial applications of arsenic include antifungal wood preservatives (e.g. for railway sleepers), pharmaceutical and glass industries, manufacture of alloys, sheep dips, leather preservatives, pigments, antifouling paints and poison baits, and agrochemical production (particularly for orchards and vineyards). Arsenic compounds are used in small amounts in the optical and microelectronics industries.

Health effects of arsenic exposure

Much of the evidence for the long-term effects of arsenic on human health comes from south-east Asia where there is a natural belt of arsenic-rich alluvium or sediments which were deposited millions of years ago in the Bramaputra and Ganges river basins. Bangladesh, parts of India, Myanmar and Nepal are all affected, and mining in areas of Thailand has also caused arsenic contamination. An estimated 30 million people may be at risk from arsenic-related disease as a result of contaminated water in the region (Caussy, 2005).

According to WHO research from south-east Asia, humans may be exposed to inorganic arsenic through soil, air, water and food. This typically includes children ingesting soil, ingesting certain traditional medicines and foods, and ingesting water. In soils in this region, arsenic is present at levels between 0.2 and 40 micrograms per gram (μg/g) of soil.

The levels of arsenic in food in affected countries vary, but a far greater threat is considered to be arsenic in drinking water. Arsenicosis (sometimes also called arsenism) is caused by prolonged exposure to low, non-lethal doses of arsenic, in the range of 0.005 to 0.09 milligrams per kilogram (mg/kg) of body weight per day (Caussy, 2005).

However, arsenic poses serious short and long-term threats to health, and so efforts to reduce exposure to arsenic from all sources are important. When individuals are exposed to arsenic over the long-term, the first changes are usually in skin pigmentation, followed by lesions and hard patches on the hands and soles of the feet. The long list of other long-term exposure effects includes peripheral neuropathy, gastrointestinal symptoms, conjunctivitis, diabetes, renal damage, an enlarged liver, bone marrow depression, destruction of red blood cells, high blood pressure and cardiovascular disease.

Long-term arsenic exposure - for more than ten years - can cause cancer, particularly of the skin, bladder and lungs, and possibly of other organs, such as the kidneys, liver and prostate. Because arsenic can pass through the placenta, pregnant women exposed to arsenic through drinking water are at greater risk of miscarriage, stillbirth and pre-term birth, and there is evidence that exposure to arsenic in the womb or in early life increases the risk of lung cancer and other lung disorders.

Sources of arsenic exposure

Arsenic can be released into the atmosphere and water by:

- Natural routes, including volcanic activity, minerals dissolving - particularly into groundwater, exudates from vegetation, and wind-blown dust
- Human activity, such as mining, metal smelting, fossil fuel combustion, pesticide production and use, and treating timber with preservatives
- Remobilisation of historic sources, such as mine drainage water
- Mobilisation into drinking water from geological deposits, e.g. by drilling wells (WHO, 2010a)

We can take in arsenic in our food, including fish, shellfish, meat, dairy products and cereals. The type of arsenic found in fish and shellfish is usually organic, which has low toxicity. The production of antifungal wood preservatives is a significant industrial source of arsenic that can contaminate soil.

The form that arsenic takes in soils depends on a number of factors, including the soil's pH, and biological activity. Where iron, clay and organic matter are present in soils, arsenic's availability becomes restricted. Even where land is contaminated, plants rarely contain much arsenic; cereals and vegetables, especially where soil is sandy, have the greatest concentrations of arsenic.

Natural processes are responsible for polluting wells in locations such as Bangladesh and Taiwan with arsenic, but in other countries, the pollution has a human source. Cornwall in the UK was once the world's largest arsenic producer, and soil in some parts of Cornwall has some of the world's highest arsenic concentrations (see Case Study 2).

Scientists are currently testing a hypothesis that some human populations have a greater tolerance for arsenic, due to genetic factors that mean they tend to process and excrete arsenic much faster than other groups. Initial studies show this to be the case for indigenous people in the South American Andes, who have lived with arsenic-contaminated drinking water for thousands of years (as evidenced by samples taken from mummies), and who carry a gene that helps to metabolise arsenic (Schlebusch *et al*, 2013).

Case Study 2. Mining's soil arsenic legacy in the UK: a possible link to skin cancer?

A European site where some of the world's highest concentrations of arsenic have been found in soils is Camborne in Cornwall, in the south-west of the UK, and is a result of mining. In Cornwall, Phillip *et al* (1984) found evidence of a cluster of malignant melanomas (skin cancers) among communities where local arsenic concentrations exceeded 30g/kg of soil. There was also a link between levels of arsenic in garden soil and in house dust.

This research raised the possibility that the relatively high incidence of malignant melanoma in the region is linked to soil levels of arsenic, an opinion suggested previously by epidemiologists looking at melanoma patterns across the UK (Clough, 1980). This area has had more than 200 years of mining history, and this combined with natural sources, has led to 722 km^2 of land with arsenic levels over 110 µg/g of soil. This is twice the maximum level expected in normal soil.

A study published in 1985 found total concentrations of arsenic in surface garden soils in the historical mining area of Hayle-Camborne-Godolphin in Cornwall were very high, and also varied widely (144-892 µg/g). Despite this, the levels of arsenic in salads and vegetables from those gardens were only slightly elevated above normal levels, and were not above the UK limit of 1 mg/kg fresh weight (Xu and Thornton, 1985). However, a further study by the British Geological Survey in 2005 on garden soils near a mine in the neighbouring county of Devon did find that growing certain vegetables posed a health risk. In particular, beetroot, celery, tomato and lettuce accumulated higher levels of arsenic (Klinck *et al*, 2005).

Current work by public authorities on arsenic in drinking water in the region in private water supplies (e.g. wells) has shown that 6% of the samples obtained from private drinking water taps exceeded Prescribed Concentrations and Values (PCVs) for arsenic, ranging between 12-435 µg per litre (µg/L). The results and possible risks have been communicated to individual householders, but the authorities noted a lack of published advice to pass on regarding long-term, chronic exposure to the elements in their particular study.

Experts have found it difficult to separate out any additional deaths or health risks from long-term, low-level exposure to arsenic in the south-west UK region from other social or medical causes. However, concerns remain, particularly about the risks of exposure to children living in former mining areas, who are more likely to ingest soil.

3.1.2 Cadmium

Health effects of cadmium exposure

Cadmium is a non-essential and toxic element for humans, and has no use for plants or animals either. It can damage the kidneys, causing excess production of proteins in the urine – the duration and level of exposure to cadmium determines the severity of the effect.

Skeletal damage is another critical effect of chronic cadmium exposure at levels somewhat higher than those where protein in the urine would be an early indicator. Cadmium is also carcinogenic if inhaled. Mainly stored in the liver and kidneys, excretion of cadmium is slow and it can remain in the human body for decades. Levels of the element tend to build up in most body tissues with age.

Cadmium is associated with skeletal damage, evidenced by low bone mineralisation, a high rate of fractures, increased osteoporosis and intense bone pain. These were features of itai-itai disease, first described in Japan in the 1940s among people who had eaten rice grown on fields irrigated with cadmium-polluted water. A low calcium diet plus high cadmium exposure led to kidney disease followed by bone disease.

Sources of cadmium exposure

Around 90% of cadmium exposure in non-smokers is through food. Crops take in cadmium from soils and the rate of uptake is influenced by factors such as soil pH, salinity, humus content, crop species and varieties and the presence of other elements (e.g. zinc). Some population groups are especially vulnerable to increased exposure and uptake of cadmium:

- Vegetarians or individuals who consume large amounts of cereals and pulses are likely to have higher exposure than the general population, as agricultural crops (especially irrigated rice) account for most of the cadmium intake
- Those with a high intake of shellfish and organ meat from marine animals may have a particularly high intake of cadmium
- People with low body iron stores, especially pregnant women, or low zinc intake have higher rates of cadmium uptake
- People with other nutritional deficiencies may also be at risk
- Smokers: tobacco plants absorb cadmium from soil, as other plants do, and are an important source of cadmium uptake. Non-smokers may also be affected through passive exposure to secondary smoke
- People living in the vicinity of industrial sources and other point sources of cadmium release can be exposed to an increased level of cadmium

According to available data, the average weekly intake of cadmium from food in most countries is within the range of 0.7–2.8 µg/kg body weight (UNEP, 2010). Given their smaller size, children may be taking in more cadmium per kilogram of body weight than adults.

In soil, the chemistry of cadmium is largely controlled by pH. Cadmium may be adsorbed on clay minerals, carbonates or hydrous oxides of iron and manganese or may be precipitated as cadmium carbonate, hydroxide, and phosphate. Under acidic conditions, cadmium solubility increases, and very little adsorption of cadmium by soil colloids, hydrous oxides, and organic matter takes place.

Both toxicity and bioavailability of cadmium are influenced by soil characteristics. Cadmium mobility and bioavailability are higher in more acidic soils, and lower in chalky/lime soils. One way to reduce cadmium bioavailability is to lime the soil to make it less acidic. However, once cadmium is in soil, it is persistent and cannot be broken down into less toxic substances in the environment.

Cadmium enters agricultural soils from the atmosphere and from application of phosphate fertilisers and sewage sludge. In heavily contaminated areas, re-suspension of dust can cause a substantial proportion of crop contamination and human exposure via inhalation and ingestion (WHO/UNECE, 2006).

Case Study 3. Mining incidents in Spain and Romania caused cadmium contamination

Major leaks of cadmium from mine tailings and waste into the environment are relatively rare, but when they do occur the local and regional impact is significant. In April 1998, the tailing dam at the Aznalcóllar mine (70 km north of Doñana National Park, south-west Spain) collapsed and the valleys of the Agrio and Guadiamar Rivers were flooded with more than 5 million m^3 of toxic sludge, dissolved in acidic water. This led to significant pollution with heavy metals, including cadmium. The bulk of the sludge was removed during the four months after the collapse, but about 0.1-5% remained, mixed with the top layer of the soil.

Cadmium levels in populations living close to the spill were slightly higher (0.19 µg/L in blood) than results from a non-affected population (0.14 µg/L) living in Seville (measured for comparison), but were still within the normal range for the general population. Levels of cadmium in smokers in the study were six times those of non-smokers, a far more significant difference.

Another example of heavy metal contamination, specifically cadmium, took place in Romania where two tailings dam failures (January and March 2000) resulted in the release of 200,000 m^3 of contaminated water and 40,000 tonnes of tailings into tributaries of the Tisa River.

Case Study 4. No apparent ill-effects from cadmium-contaminated soil in Shipham, UK

A national geochemical survey in the UK in the 1970s found high levels of cadmium, lead and zinc in and around the small mining town of Shipham in Somerset, UK. Houses had been built on land previously mined for zinc. Garden soils were tested with cadmium levels as high as 360 mg/kg (the median was 91 mg/kg), compared with typical UK soil cadmium levels of less than 1 mg/kg. Elsewhere, in the Jinzu Valley of Japan, soil levels of just 3 mg/kg had been found to cause problems with newborn babies' skeletal development, and osteoporosis in adult women. This prompted concern for local Shipham residents, and researchers carried out a number of studies on residents and their exposure to cadmium via soils.

There was evidence of cadmium at high levels in both garden soils, and in various vegetable crops grown in Shipham, however, studies at the time, and more recently, have failed to find conclusive evidence of health impacts on the local population.

Why did Shipham residents appear unaffected, while those living with far lower levels of cadmium in Japan were seriously ill? Shipham soils were slightly alkaline, which reduced the bioavailability of cadmium. In addition, although plants were taking in some cadmium, interference from other elements, such as calcium in the soil would have somewhat mitigated the quantities taken up by plants. Even so, locally-grown vegetables contained almost 17 times the national average levels of cadmium. However, local people were eating a wide variety of foods, which meant that their overall levels of cadmium intake from food were still within the WHO threshold of tolerable intake (450-500 µg/week).

Finally, it is possible that there have been health impacts, but that these have not been measured. Researchers were looking primarily at local statistics on factors such as mortality and cancer and less extreme health concerns were not considered. Many other factors, such as age, smoking, nutrient interactions, and a relatively small sample size (500 residents) make it difficult to reach a clear-cut conclusion on the impacts of cadmium in Shipham (Morgan, 2013).

The presence of cadmium in fertilisers and atmospheric deposition has been found to cause increasing amounts of cadmium in topsoil in a number of European countries (WHO/UNECE, 2006). If zinc is present, it can reduce cadmium's availability to plants, by inhibiting calcium uptake and preventing it from moving from the roots to the shoots of the plants.

Although cadmium emissions and concentrations in the air have been reduced, data from 2006 do not show reduced body burden of cadmium in non-smokers (WHO/UNECE, 2006). In the top layers of arable soil, more cadmium is typically being deposited than is being removed: cadmium is accumulating in certain soils, increasing the likelihood of future exposure through food. Cadmium levels tend to increase moving up the food chain ('bioaccumulation').

Studies in children and pregnant women are still limited, but there is some evidence that elevated cadmium exposure during pregnancy may affect a child's motor skills and perception, and that high cadmium levels in the urine of school children are associated with a weakened immune system (Schoeters *et al*, 2006).

However, more studies are needed to confirm these results. Recent research suggests that the health effects of low-level, chronic exposure to cadmium may be quite different to the high levels that caused itai-itai disease. Exercises mapping the levels of cadmium in Europe suggest correlations between cadmium and age-adjusted prostate or breast cancer rates (Pan *et al*, 2010).

The main sources of cadmium directed to landfills and waste deposits are municipal waste, cadmium processing, non-ferrous metal processing and cement production, and both industrial and municipal wastes are important sources of cadmium for landfilling.

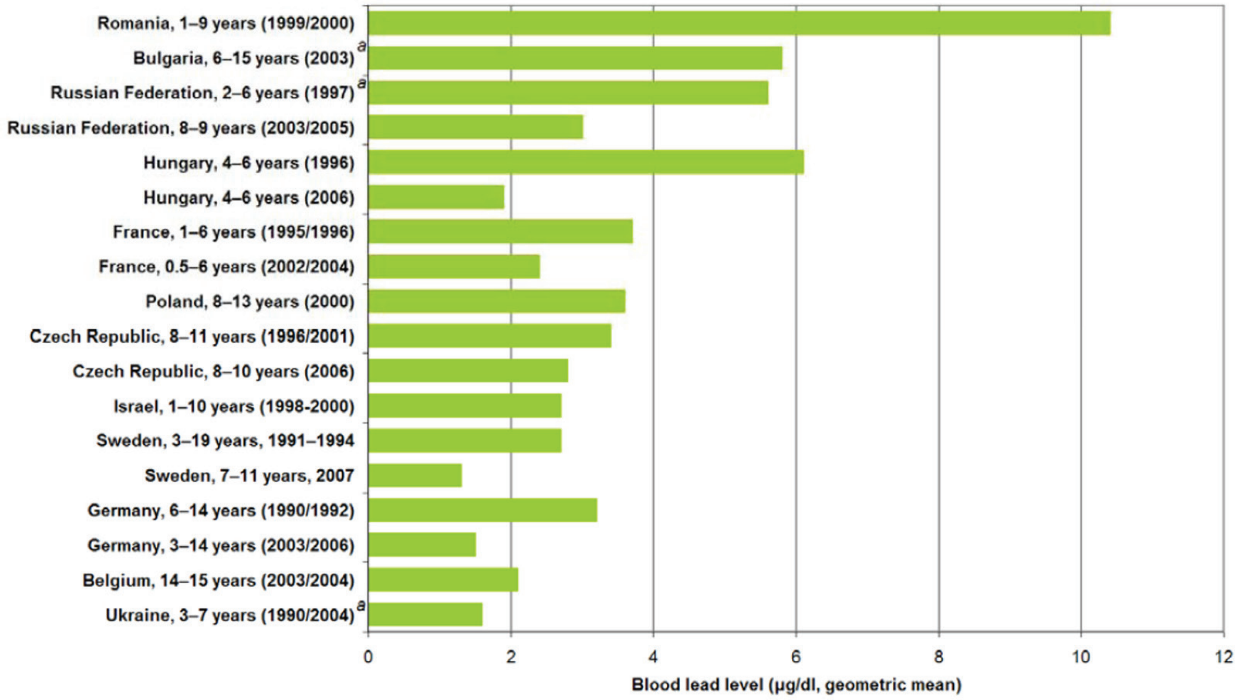
In some densely-populated countries, such as Denmark and the Netherlands, waste incineration residues, and in particular clinker, are frequently used for road construction purposes and other civil works, thereby increasing the possibility that cadmium may be spread into the environment through construction and, later, reconstruction activities (UNEP, 2010).

3.1.3 Lead

Health effects of lead exposure

Epidemiological studies show that exposure to lead during the early stages of children's development is linked to a drop in intelligence. Studies suggest that for each 10 µg/dl (microgram per decilitre) of blood lead, IQ is reduced by at least 1-3 points (Morgan, 2013. See also Canfield *et al*, 2003; Chen *et al*, 2005). This small effect on many individuals could be a significant burden to society, with reduced overall intellectual performance and resulting economic losses.

Phasing out lead from petrol has had an effect on levels of lead measured in children's blood in Europe. Soil lead and house dust, but not lead-based paint, are associated with population blood lead levels in children.



[a] Arithmetic mean.

Figure 3: Mean blood lead levels in children measured in selected areas with specific local sources of lead exposure. Source: WHO Europe, 2009.

Most soil lead and house dust are associated with leaded gasoline (Mielke & Reagan, 1998). Levels of lead in the blood began to decline earlier in the western European and Scandinavian countries than in eastern Europe, largely because unleaded petrol was gradually introduced earlier in these countries.

Besides car exhausts, industrial emissions are important sources of exposure to lead. Data from industrial areas in Bulgaria, Poland, the Russian Federation, the Former Yugoslav Republic of Macedonia and Ukraine show the significant impact of lead emitted by nearby plants on the level of lead in children's blood.

Data from the WHO (2009) provided in Figure 3 show two measurements of mean blood lead levels in children made in the same community of Veles in the Former Yugoslav Republic of Macedonia: one during the time a lead and zinc smelter plant was active (up to 2003) and a second (in 2004) after the plant had closed in the second half of 2003. Levels of lead more than halved after the smelter had ceased activity.

In Poland, the geometric mean of lead levels in the blood of children living in the vicinity of zinc and copper mills is shown to have ranged between 7.4 and 11.4 µg/dl. This is in contrast to just 3.0–6.3 µg/dl among children living in five towns where there were no industrial lead emitters (Jakubowski *et al*, 1996). In Hungary, the survey was conducted in areas previously contaminated with lead, where contamination had been due to either unlawful disassembly of used car batteries or run-off water from a lead mine. The data show evidence for the success of interventions, though there are still children with elevated blood lead levels.

Children are particularly at risk from adverse effects of lead exposure because:

- Intake of lead per unit of body weight is higher for children than for adults
- Young children often place objects in their mouths, resulting in the ingestion of dust and soil and, possibly, increased intake of lead
- Physiological uptake rates of lead in children are higher than in adults
- Young children are developing rapidly, their systems are not fully developed, and so they are more vulnerable than adults to the toxic effects of lead

Sources of lead exposure

Lead in the environment has multiple sources, including petrol, industrial processes, paint, solder in canned foods and water pipes. It can affect human health via a number of pathways, including air, household dust, street dirt, soil, water and food. Deciding which of these is responsible for exposure can be complicated, and will vary depending on the populations group and location to some extent.

Lead-containing petrol has been a major source of lead pollution and is a significant contributor to the lead burden in the body in the countries where it is still used. Most topsoils in inhabited parts of the globe are to some extent enriched with lead. Industrial emissions are also important sources of lead contamination of the soil and ambient air, and lead may also be ingested from atmospheric air or flaked paint that has been deposited in soil and dust, raising blood lead levels. In addition, food and water may also be important media of baseline exposure to lead (Tong *et al*, 2000).

3.1.4 Mercury

Health effects of mercury exposure

Exposure to methylmercury, the most harmful form of mercury to human health, affects brain development, resulting in a lower IQ, and consequently a lower earning potential (see Box 2). The long-term cost to society can be calculated as lifetime earning loss per person, although this estimate does not take into account other aspects of brain toxicity or risks of cardiovascular disease in adults. Once methylmercury is formed, it cycles though the environment for thousands of years, exposing humans and other species to potentially toxic levels for generations.

Sources of mercury exposure

Large amounts of mainly inorganic mercury have accumulated in the environment, especially in soils and oceans, as a result of these past emissions and releases from human activities. Although mercury pollution can occur naturally in the environment through events such as forest fires, most comes from the burning of fossil fuels. Usually the greatest percentage of harmful exposure to mercury for humans is through eating fish (besides direct ingestion of contaminated soil by young children).

Cement production, mining and smelting, artisanal and small-scale gold mining, burning coal and oil refining are some of the activities emitting mercury which can build up in soils. Consumer products such as electronic devices, switches, batteries, energy-efficient light bulbs and certain cosmetics, dentistry, plastic production, and the chlor-alkali industry are also contributors to mercury emissions.

After it is deposited in soils and sediments, bacteria and microbes are mainly responsible for changing mercury to methylmercury. Over 90% of the mercury found in fish is methylmercury. Mercury can enter the food chain via agricultural products or seafood. Mercury's use in agriculture has led to distressing human health incidents, which have generated data on its effects. At least 459 people died in Iraq when flour was made from grain treated with a fungicide containing mercury in 1971 (Greenwood, 1985). Children whose mothers ate contaminated bread when they were pregnant were the worst affected. Agricultural products used today may still contain mercury.

Rice crops grown in areas with high levels of coal-powered industry, mining or smelting have also shown to be affected recently. A team of Chinese and Norwegian researchers (Zhang *et al*, 2010) investigated dietary mercury contamination in rural, inland China - a region where few people eat fish. They focused on Guizhou province, which has 12 large mercury-mining and smelting operations, plus other heavy coal-powered industry. The researchers looked at mercury levels in foods eaten by populations from several locations: a village located inside a nature preserve, a region downwind of a major coal plant, people living near a defunct zinc smelter and a community whose air was polluted by mercury-mining operations. Mercury exposures for these communities varied considerably, but in every one of them "*rice accounted for 94-96% of the probable daily intake of methylmercury*". One reason is that rice paddies here contain the types of bacteria that can convert inorganic mercury to its more toxic, methylated form. The levels of contamination of rice grown elsewhere in the world, or exported, need further study.

Most mercury contamination sites are concentrated in industrial areas, but mercury can also travel long distances to locations far away from its production or use. Mercury levels in the atmosphere will fall fairly rapidly when emissions cease, but it will take many decades for levels in soils or oceans to also fall. This is why factors such as industrial legacy and historical mining, as well as geological events such as volcanic eruptions, must be considered alongside modern emissions when looking at the health impacts of mercury in soils.

The EU banned mercury exports in 2011. Under EU law, mercury that is no longer used by the chlor-alkali industry or that is produced in certain other industrial operations must be put into safe storage. Although the EU stopped all forms of mercury mining in 2001, as recently as 2008 it was the world's biggest exporter, responsible for up to a quarter of the global supply (UNEP 2013a).

Forty-two mercury-based chlorine plants remain to be voluntarily phased out or converted to non-mercury technology by 2020 at a cost of more than €3 billion. These plants account for an ever-decreasing part (31.8% in 2010) of European chlor-alkali capacity[4].

By testing museum samples, researchers can compare levels of mercury found in humans and wildlife with levels several centuries ago. Modern humans, along with other mammal and bird species, have up to ten times the levels of mercury in their tissues as in pre-industrial times (before 1800). Researchers gather this data from samples including teeth, hair, feathers and eggshells.

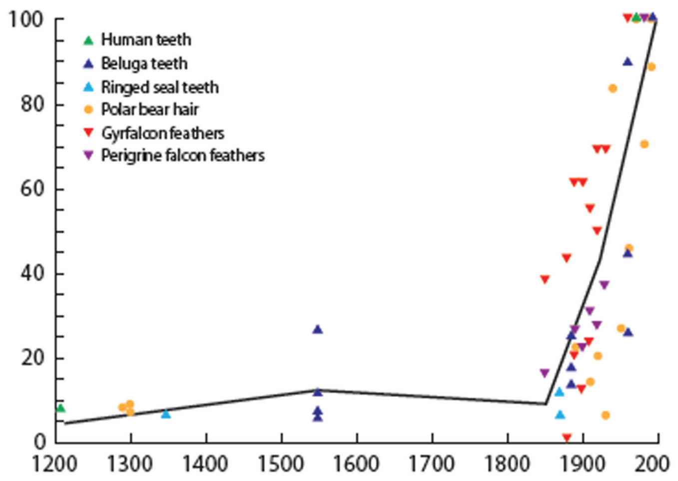


Figure 4. Historical mercury concentration as a proportion of present-day, %. Source: UNEP (2013)

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[4] *See: http://www.eurochlor.org/chlorine-industry-issues/mercury.aspx*

Box 2. European biomonitoring study highlights methylmercury exposure

Recent research (Bellanger *et al*, 2013) has estimated that 1.5 to 2 million children in the EU are born with methylmercury exposures far above the safe limit of 0.58 μg/g, and further 200,000 above the WHO recommended maximum of 2.5 μg/g. However, not every child in Europe is equally at risk. When analysed per country, children born in Portugal and Spain were the most exposed to methylmercury, and Hungary the least.

Reducing mercury pollution and cutting prenatal exposure to methylmercury could save the EU between €8 billion and €9 billion per year, the study suggests. This is equivalent to preventing exposure which leads to the loss of 600,000 IQ points every year. The majority of mercury exposure indicated by this survey related to mercury contamination from eating seafood.

The findings are from the European-scale human biomonitoring study DEMOCOPHES[5]. Teams in Belgium, Cyprus, Czech Republic, Denmark, Germany, Hungary, Ireland, Luxembourg, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, and the UK studied exposure to mercury, cadmium, tobacco smoke and some phthalates and possible relations to lifestyle, using biomarkers and questionnaire data.

Data from the study show for the first time results which are comparable across Europe. Biomarkers for chemicals of concern were measured in the hair and urine of almost 4,000 mothers and children in 17 European countries. This study is one of the first of its kind in Europe, although similar studies have been carried out in the US. It demonstrates how levels of mercury, and their potential social costs, can be quantified. However, the study deliberately avoided known 'hotspots' of contamination. It could serve as useful reference data to give background levels of contamination in European populations, against which scientists could compare people living near to hotspots – this tells us how much of their elevated heavy metal levels was due specifically to local contamination.

Human biomonitoring has proven to be an important tool for the protection of human health as it offers a direct measure of the levels of environmental chemicals in the human body. It can be used to assess and track trends (both temporally and spatially) in the level of exposure of the public to environmental pollutants and can help inform or monitor policy measures. The results from COPHES/DEMOCOPHES show variations between countries, indicating that there are differences in exposures across Europe.

[5] *http://www.eu-hbm.info/democophes*

Data, shown in Figure 4, offer us clues about various sources' contributions of mercury. The timing of long-term increases in mercury levels found in ocean life can be tied to historical events. For example, large increases in marine mercury levels beginning in the 19th century are likely to have been caused by industrialisation in Europe and North America, whereas recent jumps in the amount of mercury found in the seabirds' eggs from the South China Sea correspond to Asian industrialisation. Arctic marine animals have 10-12 times higher concentrations of mercury in their bodies than before 1800.

Mercury: knowledge gaps

According to UNEP (2013), we have considerable gaps in our knowledge about how mercury behaves in the environment, including fundamental questions about its involvement in chemical and physical processes. The extent to which mercury is released from soils into waters depends on climate and topography, and researchers would benefit from consistent data on this from around the world, to make comparisons, leading to more accurate predictions.

Many questions also remain about how mercury transfers around the whole ecosystem, including its uptake by living organisms (and people).

3.2 Asbestos

Asbestos contamination in the soil is of concern in a number of locations, because it can be released to the air by the wind or by human disturbance. Asbestos has long-term health consequences if it is inhaled, with increased mortality from lung cancer and mesothelioma the most extreme outcomes.

Disturbing contaminated soil can pose an inhalation risk, and at several US Environmental Protection Agency (EPA) Superfund sites, studies have shown asbestos concentrations of health concern may be released from soils that contain only low levels (less than 1%) asbestos contamination.

Researchers established links between asbestos exposure and lung malignancies, such as lung cancer and malignant mesothelioma (MM) several decades ago, and people living closest to mines or asbestos plants have been found to have an increased chance of contracting MM (in addition to workers at the plants, who have suffered occupational exposure). Clear cut cases have also been established of asbestos in soil causing health impacts for residents.

3.3 Dioxins and dioxin-like chemicals

Dioxins are a group of chemically-related compounds that are persistent organic pollutants (POPs). Highly toxic, dioxins accumulate up the food chain, with the highest levels found in animals at the top of the food chain (an effect known as 'biomagnification'). More than 90% of human exposure to dioxins is through food, mainly meat and dairy products, fish and shellfish.

The chemical name for dioxin is: 2,3,7,8- tetrachlorodibenzo para dioxin (TCDD). The name 'dioxins' is often used for the family of structurally and chemically related polychlorinated dibenzo para dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). Certain dioxin-like polychlorinated biphenyls (PCBs) with similar toxic properties are also sometimes labelled 'dioxins'. Scientists have identified some 419 types of dioxin-related compounds, but only about 30 of these are considered to have significant toxicity, with TCDD being the most toxic.

Health effects of dioxin exposure

Dioxins are highly toxic and can cause reproductive and developmental problems, damage the immune system, interfere with hormones and cause cancer. Dioxins are everywhere – all humans have background exposure leading to a body burden of these chemicals, which is not

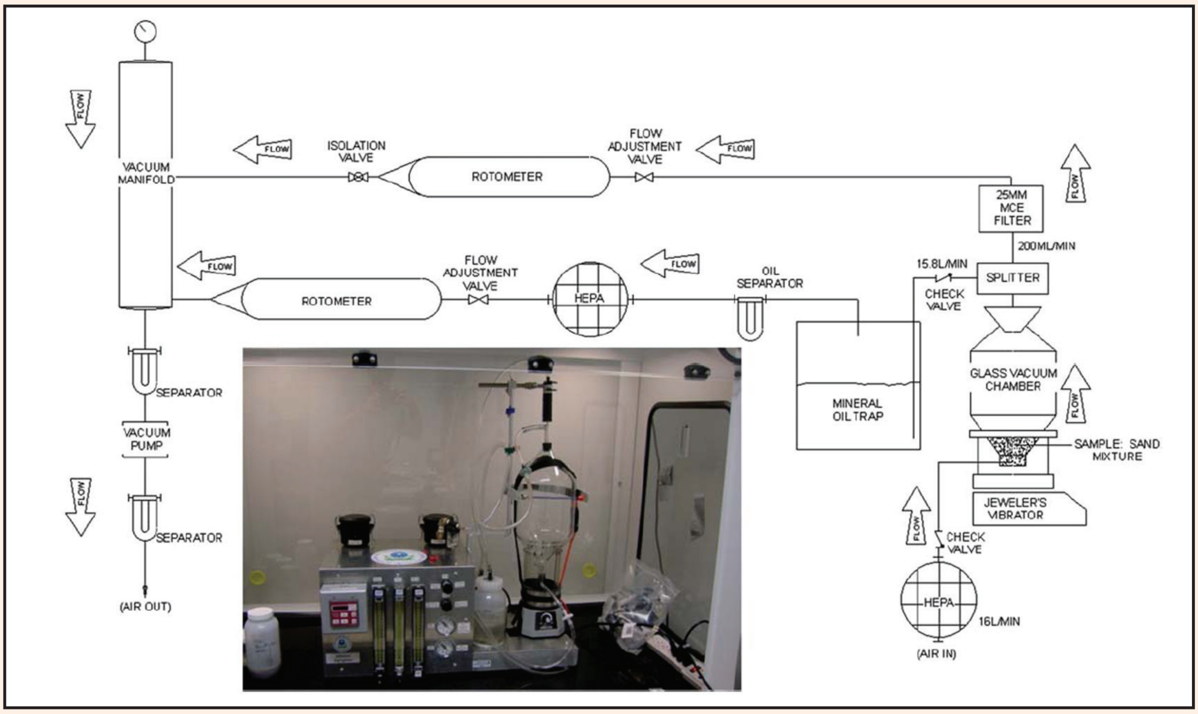
Case Study 5. Better methods to detect low levels of soil asbestos

Current methods of asbestos analysis are geared towards looking at building materials, but are not sensitive enough to detect the substance in soil. But recent work by the US EPA has increased the sensitivity of the technique 100-fold. The main route of exposure to asbestos at contaminated sites is disturbance of soil, which causes asbestos fibres to be released to the air and potentially inhaled.

Elutriation separates lighter particles from heavier ones, generally using air or water. This is a common sampling technique used for analysing asbestos. Unfortunately, water is not suitable for complex matrices like soil, and air-based methods are too time-consuming

The EPA researchers created a new method, using a fluidised-bed apparatus segregator (FBAS). Soil samples are dried, sieved, combined with sand, and then elutriated with air, giving detection limits 100 times lower than with other sample preparation methods. A lack of appropriate method to detect asbestos at lower levels has prevented scientists from fully investigating the risks from small amounts of asbestos people may be exposed to in routine situations, such as children kicking up dust while playing outdoors.

The researchers still need to carry out further work to validate and improve the new FBAS soil preparation technique (Januch *et al* 2013; Brodie, 2013).



Case Study 6. Environmental asbestos exposure in the Netherlands: cancer link investigated

Researchers from the Netherlands (Driece *et al*, 2010) recently examined cancer risks due to environmental asbestos exposure in a rural area, the municipality of Goor, where residents used asbestos to harden their dirt tracks, yards and driveways between 1935 and 1974. The material had come from a nearby asbestos cement factory, which gave the asbestos away to residents for this purpose. Soil studies showed that asbestos was still present in some locations today.

Between 360 and 4,400 tons of asbestos fibres are estimated to have contaminated the area. Within a radius of 12 kilometres, at least 83 roads were contaminated with asbestos waste, covering approximately 33,500 m^2. Residents can easily transport asbestos into their homes from the surrounding environment, carried on shoes, bicycles or pets, for example.

Air samples taken in the 1980s near the roads hardened with asbestos showed high levels of asbestos fibres (1,674 fibres per cubic metre (m^3) for samples 5 metres downwind of the road, falling to 68 fibres/m^3 at 1 kilometre from the road). Previous research based on groups of individuals occupationally exposed to asbestos has shown a mortality rate of around 10 cases of malignant mesothelioma (MM) per 100,000 persons (with 55 cases the highest estimate) for five years' exposure, starting at age 30, to asbestos levels of 5,000 fibres/m^3 per year.

The researchers applied two different methods to calculate the risk of residents developing MM. These were site-based and household exposure assessment-based approaches. It emerged that the agreement between the two methods was quite close. Using site assessment, 2.3 million person-years were at risk with average exposure below 1,674 fibres/m^3 - this would equate to 1.8 extra cases of MM per year (with 9.6 cases the maximum estimate). For the household assessment approach, 1.2 million person years would be at risk, leading to 0.9 (or maximum estimate, 5.2) extra cases of MM every year.

Because asbestos lies dormant in the lungs, typically only beginning to cause illness at least 20 years after exposure, the effects of this additional environmental asbestos exposure would have started to cause additional cases of illness in residents from 1980 onwards.

The levels of fibres in the air samples were those residents walking near the road on a dry day might expect, from dust disturbed by passing vehicles. Studies like this only offer risk levels based on average figures and behaviour. People who spent a lot of time outdoors in their polluted yards or driveways might have had higher exposure and be at higher risk of asbestos-related disease.

Meanwhile, a separate study looked at the actual asbestos-related medical cases among women recorded in the area around Goor, during 1989-2002 (Sinninghe Damsté *et al*, 2007). From a total of 28 cases of women with pleural mesothelioma, asbestos in the environment was found to be the only source of asbestos exposure for 10 women. In a further four women, environmental asbestos exposure was found to be the most likely cause. Environmental exposure was thus a factor in 64% of cases. Asbestos exposure in the area around Goor in the next 25 years is likely to result in two cases of pleural mesothelioma each year.

expected to affect human health when low. But due to the highly toxic potential of this class of compounds, reducing current background exposure is advisable. Once dioxins have entered the body, they remain for a long time because of their chemical stability and their ability to be stored in body fat (WHO 2010b).

Short-term exposure of humans to high levels of dioxins may result in skin lesions, such as chloracne and patchy darkening of the skin, and altered liver function. Long-term exposure is linked to impairment of the immune system, the developing nervous system, the endocrine system and reproductive functions. Chronic exposure of animals to dioxins has resulted in several types of cancer. TCDD was evaluated by the WHO's International Agency for Research on Cancer (IARC) in 1997 and, based on animal data and on human epidemiology data, was classified as a 'known human carcinogen'. However, it does not affect genetic material and there is a level of exposure below which cancer risk would be negligible.

Sensitive subgroups

The developing foetus is most sensitive to dioxin exposure. The newborn, with rapidly developing organ systems, may also be more vulnerable to certain effects. Some individuals or groups of individuals may be exposed to higher levels of dioxins through their diets (e.g. high consumers of fish in certain parts of the world) or their occupations

Case Study 7. PCBs in Romanian soil

Scientists in Romania have studied the soils of Central Romania, known to be contaminated with heavy metals as a result of industry (Silvia *et al*, 2012). They found that the levels of PCBs in soils, particularly in the top 20cm layer of soil, were cause for concern.

PCB emissions fell from 223.6 kilograms in 2005 to 62.855 kilograms in 2009, largely thanks to lower emissions from the lead production, pig iron and steel production sectors. Other industries in the region that contribute to PCB emissions at a lower level are zinc production, copper production, and burning carried out in the metallurgical industry, and in the residential and commercial-institutional sectors.

Although overall the levels of PCBs found were low, soils throughout the sampled area had a 'background' concentration of PCBs. Although most PCB levels decreased the deeper into the soil samples were taken, PCB 28 was an exception, and had consistently high concentrations at lower soil levels as well.

Given recent, more stringent environmental regulations, it is unlikely that levels of PCBs in Central Romania will increase further. However, the levels of PCBs in surface soils exceed the maximum intervention threshold for sensitive uses of the land - so continued monitoring will be required. At the time the research was carried out, a major metallurgical company producing zinc and lead was not operating. Despite stricter legislation, unintentional emissions of dioxins, furans and PCBs remain a future possibility in the region.

(e.g. workers in the pulp and paper industry, in incineration plants or at hazardous waste sites).

Since 1987, the WHO has conducted periodic studies on levels of dioxins in human milk, mainly in European countries. These studies provide an assessment of human exposure to dioxins from all sources. Recent exposure data indicate that measures introduced to control dioxin release in a number of countries have resulted in a substantial reduction in exposure to these compounds over the past two decades.

Levels of dioxins have decreased in Swedish breast milk samples. However, levels of the flame-retardant chemicals polybrominated diphenyl ethers (PBDEs) have been increasing. Although manufacture and new use of penta- and octa-BDE formulations is banned in the EU and China, large quantities of the flame retardants remain in consumer and industrial goods and continue to enter waste streams. There is strict regulation of this material under the EU's waste electrical and electronic equipment (WEEE) Directive, but a steady stream of e-waste is exported to Asia and Africa for recycling and disposal, where it may cause significant contamination[6].

Sources of dioxin exposure

The routes for dioxins to enter food are complex, and there are many sources. The largest source is past application of contaminated herbicides on agricultural soils. Waste incineration, industrial processes and deposition onto soils from atmospheric fallout are also significant sources, in addition to sewage sludge application.

When dioxins enter soils, they remain in the very top layer (the top 0.1 cm) with a half-life (time taken for concentration to halve) of 9-15 years. At deeper soil levels, dioxins can persist for 25-100 years. With dioxins persisting in the human body with a half-life of up to 11 years, it can be quite difficult to make direct correlations between concentrations of dioxins in human tissue and local soils (Burgess, 2013).

Although dioxins form locally, their environmental distribution is global are found throughout the world. The highest levels of these compounds are found in some soils, sediments and food, especially dairy products, meat, fish and shellfish. Very low levels are found in plants, water and air.

Extensive stores of PCB-based waste industrial oils, many with high levels of PCDFs, exist throughout the world. Long-term storage and improper disposal of this material may result in dioxin release into the environment and the contamination of human and animal food supplies. PCB-based waste is not easily disposed of without contamination of the environment and human populations. Such material needs to be treated as hazardous waste and is best destroyed by high temperature incineration.

Dioxin contamination incidents

Many countries monitor their food supply for dioxins. This has led to early detection of contamination and has often prevented impacts on a larger scale.

In 1999, high levels of dioxins were found in poultry and eggs from Belgium. Subsequently, dioxin-contaminated animal-based food (poultry, eggs, pork) were detected in several other countries. The cause was traced to animal feed contaminated with illegally disposed PCB-based waste industrial oil (McMichael, 1999).

Another case of dioxin contamination of food occurred in the US in 1997. Chickens, eggs, and catfish were contaminated with dioxins when a tainted ingredient (bentonite clay, sometimes called 'ball clay') was used in the manufacture of animal feed. The contaminated clay

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6. See: http://chemicalwatch.com/13465/electronic-waste-releases-shocking-levels-of-pbdes?q=soil was traced to a bentonite mine. Investigators speculate that the source of dioxins may be natural, perhaps due to a prehistoric forest fire (WHO 2010b).

Large amounts of dioxins were released in a serious accident at a chemical factory in Seveso, Italy, in 1976. A cloud of toxic chemicals, including TCDD, was released into the air and eventually contaminated an area of 15 square kilometres where 37,000 people lived. Extensive studies in the affected population are continuing to determine the long-term human health effects. These investigations, however, are hampered by the lack of appropriate exposure assessments. Studies have shown increases in cancer, circulatory diseases, chronic obstructive pulmonary disease and diabetes following the incident (Consonni *et al*, 2008).

TCDD has also been extensively studied for health effects linked to its presence as a contaminant in some batches of the herbicide Agent Orange, which was used as a defoliant during the Vietnam War. A link to certain types of cancers and also to diabetes is still being investigated.

3.4 Organic pollutants, including hazardous pesticides

Organic (carbon-based) pollutants include pesticides. Those that were once released into air or water will end up in soils, with the exception of those that are deposited at the bottom of oceans. Among organic pollutants some are referred to as 'POPs,' or persistent organic pollutants, which do not break down quickly in the environment.

Types of organic pollutants found in soil include:

- Polychlorinated biphenyls (PCBs)
- Polybrominated biphenyls
- Polychlorinated dibenzofurans (PCDFs)
- Polycyclic aromatic hydrocarbons (PAHs)
- Organophosphorus and carbamate insecticides (pesticides)
- Herbicides
- Organic fuels (gasoline, diesel)
- Pharmaceuticals and their metabolites

Health effects of organic pollutant exposure

Canadian reviews of a wide range of research data (Bassil *et al*, 2007; Sanborn *et al*, 2007) show that health effects of organic pollutants could include the following:

- Individuals with increased exposure to pesticides (e.g. farmers, landscapers) appear to be at greater risk of non-Hodgkin lymphoma. Studies have also shown a greater risk among children from homes where pesticides are frequently used, or otherwise subject to higher exposure.
- Some studies have linked leukaemia, particularly in children, with insecticides. Timing of exposure is significant, with children exposed in the womb most likely to be affected. Pesticides have also been linked to brain cancer in children whose parents are exposed to high levels of pesticides, for example, through work.
- Some studies have linked pesticides to breast cancer and benign breast changes, although other studies have produced findings that disagree.
- Researchers have linked pesticide exposure to kidney cancer and pancreatic cancer.
- Several studies have linked pesticides to increased risks of prostate cancer, particularly relating to the fumigant methyl bromide.
- Links have also been made between stomach cancer and atrazine (Bassil, 2007).
- Long-term effects of pesticides on the nervous system include cognitive and psychomotor dysfunction, and neurodegenerative and neurodevelopmental effects. Pesticide poisonings result in well-described acute and chronic neurotoxic syndromes. Chronic effects from low or moderate exposures have been less well documented.
- Many studies have shown that occupational pesticide exposure could increase the risk of later developing Parkinson's disease.
- Studies have consistently shown an increased risk of birth defects resulting from parental exposure to pesticides. The majority of studies looking at the effects of pesticides on foetal growth showed that agricultural pesticides altered foetal growth, and increased risks of miscarriage.
- Those exposed to pesticides also had a greater frequency of chromosome aberrations (genotoxic effects), although it is hard to separate these effects from other sources of genetic damage, such as smoking, alcohol or radiation (Sanborn *et al*, 2007).

However, we are seldom exposed to just one of these chemicals or in high doses – most people are exposed to a complex mixture of these chemicals at low concentrations (see footnote 3, p9). Toxicology tends to be a science dealing with individual poisons and some experts say that understanding the risks from multiple agents is the greatest challenge to modern toxicology.

Overall, few studies have been conducted on the toxicity of complex chemical mixtures in soils. The effects of the soil and organisms within it upon organic pollutants are unknown. The data that do exist tend to be on short-term, high level exposure of these chemicals, which is less relevant to the potential low-level, long term health impacts from living near to contaminated soil (Burgess, 2013).

Due to the unethical nature of cause-effect studies on pesticide exposure, the growing body of research on pesticide health effects cannot be used to establish a cause-effect relationship between the use of pesticides and health effects.

Synthetic organic chemicals often include atoms (such as chlorine, bromine or sulphur) that have been inserted into their structures in positions not commonly found in nature. This is one of the factors that makes synthetic organic chemicals hard for natural processes to deal with – they are toxic to living creatures and do not break down easily. As well as persisting in the environment, this also means that they can build up over time in body tissues, or become magnified along food chains.

The chemical industry creates (or previously created) these compounds in very large quantities, to use in a wide range of products including plastics, refrigerants, preservatives and pesticides. Many POPs are actually by-products of these processes, and are not useful in their own right. Examples include dioxins, and polychlorinated dibenzofurans (PCDFs).

Case Study 8. Decline in soil POPs in Norway and the UK

The overall concentrations of some persistent organic pollutants (POPs) in soil have declined in Norway and the UK since the ratification of the Stockholm Convention by the EU in 2004 (Schuster *et al*, 2011).

Researchers compared POP concentrations in soil samples taken from 70 rural locations in Norway and the UK in 1998 and again in 2008, analysing changes in the concentrations of polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and organochlorine pesticides.

There was little change in the concentrations or distribution of organochlorine pesticides concentrations over the ten years. However, the overall concentrations of PBDEs and PCBs had both fallen, with PBDEs showing the strongest decline to less than a quarter of levels measured in 1998.

Primary sources of some POPs in soils have been reduced for these two countries in recent years, such as industry and substances including paint and adhesives. However, primary emissions for PCBs are still too strong and that this should be addressed in future.

Soil plays an important role in the fate and distribution of POPs and can act as a sink or a source. POPs can be transported around the world in the atmosphere, and deposited in soil at significant distances from their original source and, in turn, soil can re-emit POPs to the atmosphere and be moved on again. However, uncertainties remain surrounding POP distribution, degradation and circulation between air and soil.

4. Methodological issues: difficulties in measuring soil contamination and health impacts

There are many methodological issues around soil sampling, background exposure levels and health study design that are beyond the scope of this report to examine in depth. However, a few key issues are listed here to help put the complexity of the science involved in context.

4.1 Background intake

This report mainly considers the health impacts from individual, point sources of soil contamination. However, knowledge of the level of that contaminant in soil and human susceptibility in its presence does not give an accurate picture of the toxicological risk to humans, and only indicates risks originating from the soil. To get an idea of the true public health risk, other sources that people are exposed to alongside soils must also be taken into account. This 'background intake' may come from food, drinking water, or air pollution levels. Individual behaviour, such as smoking, unusual diet or occupational exposure may also contribute to the overall impact on health from soil contaminants (Environment Agency, 2009).

4.2 Soil depth, sampling and use

Levels of contaminant vary depending on soil depth. Whether the soil has been moved or landscaped will also have an impact. Standardised sampling methods are important as a site will not necessarily have a uniform distribution of contaminants throughout its soils, so the levels, and risks, will vary from one area to the next. In cases of sampling at a large plant or facility, accurate measurements of contamination levels at the site may not be possible until the plant has been decommissioned and the site cleared.

4.3 Physical and chemical processes

The behaviour of contaminants in soils depends on several physical and chemical processes:
- Reduction/oxidation (redox)
- Absorption
- Precipitation
- Desorption

Whether a soil absorbs or releases a pollutant depends on:
- Types of mineral present
- Amount of organic material present
- Soil pH (acidity)
- Redox potential
- Moisture

How effectively contaminant molecules bond with the surface of the soil (absorbs) is important when considering the human health risks. A strongly-bonded contaminant will be less likely to leach out of the soil into groundwater, or be released from the soil as a vapour than one that is weakly bonded. These properties relate to the contaminant's bioavailability (see Section 4.4).

In contrast to their behaviour in air and water, pollutants in the soil do not generally disperse quickly. They often form discrete pockets of pollution (hotspots). Soils are made up of solid, liquid and vapour phases. How the pollutant is divided between these phases will determine how it behaves, and what types of environmental and public health risk will result (Kibble & Russell, 2010).

4.4 Bioavailability and bioaccessibility

Estimates of soil toxicity depend on the techniques used to measure them, and the interpretation of the results. A case study which illustrates this is provided by England's Environment Agency who took a soil sample previously tested in humans ('*in vivo*') and distributed it to several laboratories for testing. The Agency also sent three further soil samples with varying levels of arsenic, lead and nickel to laboratories. The aim was to compare the results the laboratories gave regarding bioaccessibility estimates, and total metal concentrations using their standard procedures.

In general, the laboratory results agreed well with one another. However, an important finding was that, based on the sample previously tested on humans, most laboratories were underestimating the bioaccessibility for lead in the sample using their laboratory methods.

Scientists working in land contamination risk assessment frequently use '*in vitro*' (laboratory only) tests to estimate bioaccessibility of contaminants from the soils on their sites. Most risk assessment models, including the Contaminated Land Exposure Assessment (CLEA) model, use exposure estimates based on intake, rather than uptake. 'Intake' is defined as the amount of a substance an individual is exposed to (in weight per kg of body weight per day), and 'uptake' as amount of a substance taken up by the body that enters the bloodstream (in µg/100ml).

Box 3. Bioavailability and bioaccessibility definitions

Bioaccessibility: The fraction of a substance that is released from soil during processes like digestion into solution (the so-called bioaccessible fraction)

Bioavailability: The fraction of the chemical that can be absorbed by the body through the gastrointestinal system, the pulmonary system and the skin.

Source: www.eugris.info/glossary.asp

It is important to understand that a soil guideline value (SGV) is a figure for the concentration of a contaminant in the soil that sets off 'possible risk' alarm bells. It means that further investigation and/or risk management are needed. These SGVs are generally derived from estimates of toxicity from a certain human intake of the soil rather than actual human uptake of the contaminant. For example, a child may ingest some soil containing a quantity of a heavy metal known to be above risk levels for negative health impacts, which is classed as the intake. But the percentage of that heavy metal that is actually taken in and processed by the child's body is the uptake.

As soil properties may vary considerably from one site to another, even if two soils contain the same levels of a certain contaminant, the bioavailability of that contaminant to humans may be quite different, depending, for example, on how tightly the chemical is bound to the soil.

Two different definitions of bioavailability are used in human health risk assessment:

Absolute bioavailability

The percentage of an external chemical dose that reaches the bloodstream (the ratio of internal dose to the administered dose) (Hrudy *et al*, 1996). A practical example of this calculation would be:

$$\text{Absolute bioavailability (\%)} = \frac{\text{Amount of contaminant absorbed by the body}}{\text{Concentration of contaminant in the ingested soil}} \text{x100}$$

Relative bioavailability

This compares the absolute bioavailabilities of different forms of a contaminant, or exposure to different media containing a contaminant. This is important for soil studies, because the chemical form that the contaminant takes in the actual sample of soil in question, as well as the makeup of the soil itself, could differ considerably from the 'reference' sample used to derive the established risk limit values for that contaminant in soil (Environment Agency, 2007).

$$\text{Relative bioavailability (\%)} = \frac{\text{Absorbed fraction from soil}}{\text{Absorbed fraction from the dosing medium in the toxicity study}} \text{x100}$$

Long-term vs. short-term stability

Some contaminants can be extremely long-lived in the environment, as noted. The complexity of calculating not just the current risk from a site, but also its future risks, is considerable. A great deal depends upon the stability of the chemical contaminants in the soil over time, and upon the site's future uses.

Case study 9. Comparing arsenic bioavailability and bioaccessibility in Spain

Very few studies have tried to relate arsenic bioaccessibility (the fraction of a contaminant that is soluble in the mouth or digestive system and available for absorption) with arsenic bioavailability (the fraction of an administered dose that reaches the bloodstream).

Researchers in Spain have recently determined the concentrations of bioaccessible arsenic in mining-influenced soils in southeast Spain (Martínez-Sánchez *et al*, 2013). Coastal soils with a strong mining influence are often intended for residential use (with inland areas more often used for agriculture). It is important to quantify the risks posed by arsenic (and other heavy metals) in soil to determine whether to grant permission for residential building on the land.

The scientists analysed 26 soil samples. This revealed a wide range of concentrations, both for larger soil particles (6.9-347 mg/kg, average value 61.5 mg/kg) and typically higher levels of arsenic in the smallest particles (2.7-450 mg/kg, average value 116 mg/kg). The researchers recommend that the size of soil particles should be taken into account when considering health risks, since the smallest size particles (<250 µm) typically stick to children's hands. They also found that while the levels of arsenic present as a total concentration might be cause for alarm, the actual levels that were bioaccessible were lower. They therefore highlight the importance of using a suitable methodology to establish the risk in a reliable way.

In other words, high levels of a heavy metal in soil may only pose a relatively low risk once the chances of it entering the body, plus the actual amount a person can absorb, are considered. The actual amount absorbed will be specific to the location, type of soil, climate and specific use of the land.

Case study 10. The legacy of the First World War written in Belgian soils

Recent research in Ypres, Belgium, has revealed that First World War (WWI) activities created localised hotspots of heavy metal contaminated soil evident today (Meerschman *et al*, 2011). Levels of copper and lead in particular correlated with wartime activity, caused by corroding shell fragments.

The researchers considered a number of other possible sources for the contamination, including previous metallurgical activity and addition of sewage sludge to the soil. However, these were ruled out, and WWI activities were identified as responsible for the elevated concentrations of copper, lead and zinc.

The scientists who conducted the study believe that this was the first time the impact of WWI on multiple heavy metal concentrations was investigated at a landscape scale based on a large number of soil samples. Even though the soil around Ypres is, in general, not contaminated, the war left specific areas enriched with the metals.

In addition to encouraging other researchers to look into war activities as a possible source of soil heavy metal contamination, the study also serves as a reminder that we may need to look back to activity over decades, if not centuries, to understand how land was used, and whether there could be any associated risks today.

5. Summary

This report provides an overview of research, with the aim of offering more scientific detail for decision makers regarding the possible health impacts of soil contamination. This exercise draws attention to a number of studies on incidents of known soil contamination, most of which have been carried out in the past few decades.

The joined-up field of linking the state of our soil to our health, and the related long-term costs associated with this, is relatively new. Therefore, researchers in diverse fields with expertise in soil science, health, toxicology, and other disciplines need to collaborate and share their findings to take this area forward. It is notable that for some known toxic contaminants, only one or two large-scale and long-term case studies exist, and that these are invariably linked to major disasters or geological factors leading to spikes of contamination. To properly understand our relationship with soil in a post-industrial society, much more data from soils and communities in large, well-managed studies over long timescales are needed if we are to begin to see the true patterns of health impacts emerge.

We are already beginning to see the longer-term trends and impacts of our industrial heritage and previous activities. Levels of mercury in the environment are rising due to previous waves of industrial activity. Levels of some POPs are declining several years after they have been phased out. More recent industrial activity in regions, such as China, is showing us new routes of exposure via soils, as in the case of exposure from a rice diet grown in contaminated areas. Furthermore, data on First World War sites and historical mining areas show us that significant care needs to be taken when deciding where to site modern-day activities, as some contaminants can still be detected at potentially toxic levels a century after contamination has ceased.

It is important to understand why a site-by-site approach to assessing risk is needed, which takes into account the individual environmental characteristics of soils and human activities. Each site has a unique risk profile, a unique chemistry and a unique history. While contamination does not necessarily spell disaster, only further research on a case-by-case basis can offer peace of mind.

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