Treatment and Management of Contaminated Soils in Switzerland

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Abstract
Switzerland is a small, mountainous country in the heart of Europe. Due to high population density, unrelenting demand for new building land, and scarcity of land resources, there is continuing pressure on the small fraction of cropland to be used for building and infrastructure. In response, the protection of fertile soil has received increasing attention in the last fifty years. Still, the trend of converting agricultural land into residential, traffic, commercial and industrial areas is continuing at an alarming rate. All the more it is also important that the quality of the remaining open land in rural as well as urban areas is protected against contamination and other forms of degradation. In this paper, we review the concepts underlying the Swiss legislation relating to soil protection, how they have been translated into regulations, how these are implemented in practice, which new soil pollution problems have emerged in recent years and how they may be addressed in the further development of soil protection in Switzerland.

Keywords: soil contamination, Swiss legislation, soil fertility, ecological soil functions, sustainable land management

1 Introduction

Switzerland is a small country in the center of Europe. It is rich in mountainous landscapes and a humid, temperate climate. Around 37% of the total surface area of 41’285 km^2 are classified as agricultural area, but this includes also areas that can only be used as grassland, such as alpine pasture. Only a small fraction of the land is suited for use as arable land. This land is located in the valley bottoms and the so-called Swiss Plateau stretching as a narrow band from the southwest to the northeast of the country between the Alps in the south and the Jura mountain chain in the northwest. As these areas are also those that are best suited for settlements, traffic and other infrastructure, industry, and commercial purposes, there is a strong pressure on the arable land to be converted to these forms of land use. The Swiss Federal Law on Spatial Planning, which demands that land is used efficiently and that land resources such as soil fertility need to be protected, did hardly slow down the loss of fertile soil to building areas. According to official statistics, 851 km^2 of agricultural land were lost in the period from 1985 to 2009 (FSO, 2013). Most of this loss was due to conversion to residential, traffic, comercial and industrial areas, which increased by 584 km^2 at the same time. The difference was accounted for by transition of abandoned grassland to regrowth of forests in the mountains. Due to the very limited fraction of land suited as agricultural cropland, it is all the more important to stop this trend and to protect the quality of the remaining cropland against degradation and pollution.

2 Qualitative and quantitative soil protection in Switzerland

Apart from soil loss due to sealing for traffic areas and construction of buildings and infrastructure, which is essentially irreversible, the main threats to soils in Switzerland are erosion, in particular water erosion and slides, compaction and degradation of soil structure due to intensive use of heavy agricultural machinery, and pollution by the input of chemicals with the application of agrochemicals, manures and composts and the deposition of gases, dusts and aerosols emitted from traffic, household, and industrial processes after transport over shorter or longer distances through the atmosphere. In the 1970ies, soil pollution through atmospheric deposition attracted most attention among these impacts on soil quality, and concern about the future of soil fertility finally led to the Swiss Federal Ordinance Relating to Soil Pollutants (OSP) from 9 June 1986, based on the Federal Law for the Protection of the Environment from 1983.

To understand the concept of the OSP, it is helpful to consider that Switzerland is composed of 26 formerly independent states, called cantons, which agreed in 1848 to form a federation, similar in many aspects to the USA. In fact, the constitution of the US served in many respects as a model for the constitution of the Swiss federation. One of the principles is that the federation can take over only competences that are explicitly assigned to the federation by the constitution. In general, the federal constitution formulates a framework within which the cantons can set their own regulations, as long as they do not violate the minimum standards set by the framework. In particular, the cantons are also responsible to enforce the regulations. The federation can also motivate the cantons to participate in federal policies by giving financial support. Thus, the federation is funding basic research and operating nation-wide environmental monitoring networks, while cantonal environmental protection agencies are responsible for case-specific regional and local surveys and monitoring programs.

Secondly, when talking about soil protection, it is important to bear in mind that a distinction is made between quantitative and qualitative soil protection. This distinction does not only apply to Switzerland, but also to other countries. Qualitative soil protection relates to the soil quality of land not used for building purposes. In Switzerland, it is primarily regulated by the legislation on environmental protection, in particular the OSP and enforced by cantonal soil protection agencies that are usually part of an environmental agency. Quantitative soil protection is the domain of spatial planning, which is the political process of the spatial assignment of land to building areas with residential, commercial and industrial zones and to areas assigned to non-building zones, including agricultural, forest and other areas. The plans are prepared and updated by spatial planning agencies. These are responsible to assure that the guidelines provided by the federal legislation on spatial planning are observed, but in reality, the law does not provide sufficient protection of environmentally precious soil resources against the political pressure of economic interests (Grêt-Regamey *et al.*, 2017). A major problem here is that soil quality is not used as a criterion for the assignment of land use zones (Greiner *et al.*, 2017).

Thirdly, it should be noted that a distinction is made in Swiss legislation between contaminated soil and contaminated sites. Soil protection according to Swiss legislation relates to all land that is or can be used for any kind of plant production or growth of natural vegetation, including cropland, grasslands, forests urban, gardens, and uncultivated land. Soil contamination of these types of land usually result from atmospheric deposition of contaminating substances or excessive inputs of compounds and materials applied with their cultivation. Such contamination is usually diffuse, not well delineated, concentrated in the topsoil and rarely reaching deeply into the soil. Generally, the main problem is the potential damage to the quality of the affected soil as an environmental resource, including its productivity. Concern was initially primarily about persistent contaminants of low mobility that tend to accumulate over time and have wide-spread distribution, such as in particular lead, cadmium and some other heavy metals. Due to the usually slow rates of accumulation, the wide-spread distribution of these contaminants and the lack of cost-effective, non-destructive in-situ methods to clean-up large areas of contaminated soil, the focus of the OSP was entirely on prevention of further contaminant accumulation by stopping further excessive inputs.

In contrast, contaminated sites are locally well-defined sites of industrial or commercial facilities, waste disposal or accidents contaminated with hazardous chemicals at concentrations that pose acute health risks through dispersion into water, air and food chains and thus are urgent to be treated and remediated. Problem contaminants are in particular substances of high toxicity and mobility such as volatile halogenated and non-halogenated hydrocarbons. Contaminated sites include the soil of the site, but usually also the subsurface and in the case of industrial and commercial sites also the buildings. In many cases, the contamination is deep-reaching and often extends into aquifers. While contaminated site remediation generally also includes soil treatment, the focus here is not on the restoration of soil quality but on the elimination of hazards to human health and well-being.

For more information on the concepts underlying soil protection in Switzerland, including the legislation relating to qualitative soil protection presented in the following, readers are referred to Karlaganis (2001) and SAEFL (2001).

3 The Ordinance Relating to Soil Pollutants (OSP) from 9 June 1986

The motivation underlying the OSP to protect soil as an essential resource of agricultural production is reflected in the fact that soil fertility (and not soil quality in general or soil itself) is specified as the object to be protected. The legal definition of soil fertility, however, is rather wide, covering also aspects of soil quality beyond mere productivity in the sense of soil cultivation. Thus, it relates also to aspects such as biodiversity and the biogeochemical cycling of carbon and nutrients, and with respect to plant production it does not only relate to the quantity but also to the quality of the products. According to the OSP, “soil is fertile, if

- it enables the existence of a diversified and biologically active community of soil organisms, has a physical structure that typical for the site, and has an intact capability to decompose organic residues and chemical compounds;
- naturally occurring or cultivated plants and plant communities can grow and develop normally, and their characteristic qualities are not affected adversely;
- crops grown for human and animal consumption are of good quality and do not present a health hazard."

To protect the fertility of soils against adverse impacts of contamination, the OSP defines three tasks: (a) soil observation and monitoring, (b) evaluation of the results, (c) interventions in areas with excessive contamination.

The observation of soil contamination occurs on two levels: (1) A national soil monitoring network is operated by the federation (NABO) for reference purposes. (2) Monitoring of areas with increased contamination is performed by the cantons. The NABO is based on a nation-wide network of 105 monitoring sites across Switzerland (Gubler *et al.*, 2015a). The sites were selected judiciously to represent all major climate and physiographic regions, landscapes and land use types. As the purpose is to serve as a reference base of the general soil contamination status for the respective regions and types of land-use, sites specifically influenced by local point sources were not included. The topsoil of the sites is sampled at regular 5-year intervals. In addition to the analysis of soil samples, the NABO also collects information relating to contaminant fluxes into and out of the topsoil of the sites, including atmospheric deposition and the application of fertilizers, manures and pesticides by farmers on agricultural sites. This dual monitoring approach of assessing both the status and fluxes of elements and compounds under observation has been applied at NABO sites up to now for phosphorus (Della Peruta *et al.*, 2014, Della Peruta and Keller, 2016), heavy metals (Gubler *et al.*, 2015a; Bigalke *et al.*, 2017; Imseng *et al.*, 2018), PAHs (Gubler *et al.*, 2015b), and pesticide residues in soil (Chiaia-Hernandez *et al.*, 2017).

Apart from providing reference data for more detailed surveys of the cantons in areas with locally increased concentrations of soil contaminants, the NABO serves to inform policy-makers, regulators and the public about the efficiency of emission control regulations in keeping inputs of soil contaminants at a sustainable level and if necessary to tighten respective emission control thresholds.

In order to facilitate and standardize the evaluation of survey and monitoring results, the OSP defined "guide values" for a number of heavy metals and fluoride. In addition to guide values relating to the so-called "total" concentration of the contaminant, guide values were also defined for the concentration of an easily extractable (available) fraction ("soluble concentration") for some contaminants. It defines the threshold concentration of a contaminant in the topsoil above which soil fertility must be considered by the authorities as endangered in the long term. If guide values are given for both, the total and the soluble concentrations of a contaminant, then soil fertility is considered endangered as soon as one of the two is exceeded. As the guide values were issued to indicate hazards to soil fertility, the exceedance of a guide value does not necessarily imply a health risk for humans or animals.

In the case that a guide value was found to be exceeded or that soil fertility was found to be threatened in the long run due to a trend of excessive accumulation, the interventions foreseen by the OSP were limited to request monitoring of the situation by the cantons and, if considered necessary, tightening of emission control measures based on other regulations such as those relating to air pollution, water protection, the handling of chemicals including biowastes, and others.

4 From the OSP to the Ordinance Relating to Impacts on the Soil (OIS)

Despite the limitations in possible interventions, the OSP was successful in pushing authorities to implement and improve contaminant emission control and get cantons setting up the NABO and soil protection offices surveying and monitoring soil contamination. As a result, in particular the input of heavy metals via atmospheric deposition and agricultural applications of biowastes, manure and commercial fertilizers substantially decreased and is not considered a major problem of general importance nowadays.

Application of the OSP in practice also revealed some major shortcomings though. The OSP did not provide a legal basis allowing the remediation and restoration of contaminated soils to be requested. The philosophy was that other laws and regulations based on them, e.g. relating to food quality, water protection, waste treatment, use of chemical products and other materials, forestry, nature protection etc., would be sufficient to oblige a landowner or a polluter to remediate a contaminated soil in order to avert emanating health risks. However, experiences showed that there were various situations in which this framework of regulations did not provide sufficient protection against health risks. This was for example the case for direct soil consumption especially by small children in gardens or on playgrounds with contaminated soil, or uptake of toxic metals via crops from fields which had been contaminated already in the past with highly contaminated sludges or other wastes.

When in the 1990ies increasing physical impacts on agricultural soils through compaction, structure degradation, erosion, landscaping and improper recultivation were found to require a revision of the OSP, the opportunity was taken to close also the loopholes pointed out before relating to health risks from contaminated soils not covered by other regulations. To make the extension in scope visible, the revised ordinance, which came into force on 1 July 1998, replacing the OSP, was titled Ordinance Relating to Impacts on the Soil (OIS). In the following, only aspects relating to soil pollution are presented, while all points relating to physical and biological impacts on soil covered by the OIS are omitted here.

As for technical legislative reasons the objective of the OIS had to remain the protection of soil fertility, expanding the goal to include also the protection of humans and animals against health risks resulting from direct uptake of contaminated soil required an extension of the definition of soil fertility. Thus, the following condition was added as a fourth criterion to the other three criteria already given in the OCS: Soil is fertile, if

- it enables the existence of a diversified and biologically active community of soil organisms, has a physical structure that typical for the site, and has an intact capability to decompose organic residues and chemical compounds;
- naturally occurring or cultivated plants and plant communities can grow and develop normally, and their characteristic qualities are not affected adversely;
- crops grown for human and animal consumption are of good quality and do not present a health hazard."

Furthermore, to provide a basis for the enforcement of hazard eliminating actions, two further categories of threshold values were introduced in addition to the guide values: trigger and remediation values. While the guide values were kept at the lowest level to indicate thresholds of contaminant concentrations above which soil fertility is considered to be endangered in the long term, these new values defined two levels above which health hazards for humans, animals and plants must be considered as possible (trigger values) or as given (remediation values). In contrast to the guide values, trigger and remediation values are specific for certain types of soil and land use, accounting for the fact that health hazards depend on exposure pathways which depend on soil and land use. As in the case of the guide values, trigger and remediation values are defined for total, soluble or both types of contaminant concentrations, depending on the contaminant and the exposure pathway.

If a trigger value is exceeded, then a case-specific investigation is necessary to determine if and what kind of soil/land use restriction may be needed to avoid adverse health effects. If a remediation value is exceeded, then the hazard must be eliminated by soil remediation or land use change. Land use change is an option only if it is compatible with the spatial planning law and if it can be guaranteed that it will eliminate the hazard.

5 Remediation of contaminated soil

While the OIS provides a legal basis that gives authorities the power to demand the remediation of a contaminated soil if a remediation value is exceeded and land use change not possible, it does not give any guidelines how to do it, but leaves it to the polluters or landowners, if no polluter can be made liable, to find a method by which the contaminated soil can be remediated within reasonable time at costs that are affordable and with a minimum of other adverse environmental impacts.

In principle, hazards from contaminated soil can be controlled by

- cutting off exposure pathways to risk receptors through change in land management and prevention of access (safeguarding),
- contaminant inactivation or immobilization, including prevention of contaminant dispersal with erosion and leaching by means of soil stabilization and hydraulic control
- in-situ clean-up through removal of the contaminants or their irreversible transformation into harmless compounds, or exchange of polluted with clean soil

Cutting-off exposure pathways and contaminant immobilization bear the risk that the contaminants are still present in the soil and could become mobile again over time. Similarly, inactivated contaminants may become active again with changing conditions or with ageing just over time. Only irreversible transformations of the contaminants into harmless compounds or their removal either by in-situ clean-up or soil exchange are truly definitive solutions.

Irreversible destruction only works with organic contaminants and even many of these are very resistant against chemical or microbial attack, and it is very difficult to control such processes under in situ conditions. Furthermore, contaminations rarely involve only one compound or just one group of chemically very similar compounds. Commonly, contaminated soils contain a mix of contaminants including metals. Metals cannot be destroyed chemically and simultaneous inactivation of different metals is often not possible for chemical reasons. For example, sorption of metal cations to mineral soil surfaces increases with decreasing pH, but acidification promotes the desorption of metal oxyanions.

Thus, soil with contamination by metals and persistent organic pollutants is usually treated ex situ in specialized facilities after excavation. Due to the generally high costs of such an operation, this approach is only used in practice where the treated material has a high economic value of re-use, which is usually for construction purposes. The main type of ex-situ treatment of contaminated soil thus is washing, as the principle of this method is to separate the fine particles, which usually carry the by far largest fraction of the contamination, from the coarse particles to get sand and gravel fractions clean enough for re-use as construction material. The residual fine fraction, in which almost the entire contamination is concentrated, is either directly land-filled or as ash after the destruction of organic contaminants by incineration, if that is possible. This is only the main type of treatment for contaminated soil that cannot be cleaned by washing for technical reasons or which does not contain a sufficiently large fraction of sand and gravel to yield enough re-usable product.

Techniques developed to decontaminate soils of contaminated industrial sites are generally not suited to remediate contaminated soil for re-use in agriculture. In addition to the costs, the main reason is that the harsh treatments applied to remove metals and persistent organic contaminants with these methods generally destroy also those components of a soil that are instrumental for its fertility. Restoration of soil fertility after decontamination requires gentle remediation techniques that enable the treatment of large areas at comparatively low costs and preserve the basic components of soil fertility, in particular pedogenic minerals, organic matter and structure.

As soil fertility includes the capacity to enable plant growth, remediation methods based on plants, summarily referred to as phytoremediation, are implicitly compatible with the goals of gentle soil remediation. Much hope has been placed in particular on the potential use of plants to extract metal contaminants from polluted agricultural soils, as there are plants, called hyperaccumulators, which have the capacity to extract inordinate amounts of metals from soils and accumulate them in aboveground tissues, where they can be easily harvested. Unfortunately, these hopes have not been fulfilled except for a few very special cases. For some of the main metal contaminants, such as lead, copper and chromium, there are no known or cultivable hyper-accumulator plants, and the hyperaccumulator plants known for other metals such as zinc and cadmium produce so little biomass that their decontamination efficiency is not superior to non-hyperaccumulating crop plants with high-biomass production. A notable exception is the South African nickel (Ni) hyperaccumulator *Berkheya coddii*, which can produce more than 20 t harvestable biomass per year and accumulate more than 10 g kg^{-1} (=10’000 ppm) Ni in it (Robinson *et al.*, 1997; Keeling *et al.*, 2003).

While *Berkheya coddii* is suited for the “phytomining” of Ni from soils with high Ni concentrations and thus, for example, to recycle Ni from soils contaminated by dust deposition around Ni smelters, even such a performance would not be sufficient to clean up a highly contaminated soil within an appropriate time span. This can be illustrated by a simple calculation: Let us assume that the metal concentration of a contaminated topsoil (0-20 cm depth, bulk density 1.4 t m^{-3}) shall be decreased by 2000 ppm within 20 years, i.e. by 100 ppm per year, and that the plant yields an annual aboveground biomass of 14 t ha^{-1}. This means that the metal must be accumulated at a concentration of around 20’000 ppm to achieve the clean-up goal, with the underlying assumption that this rate can be maintained independent of the achieved decrease in the metal concentration of the soil. The latter assumption is unrealistic, as it ignores that with decreasing concentration also the bioavailability of the metal will decrease and at some level become a limiting factor for uptake.

The fact that even the performance of high-biomass hyperaccumulator plants would in general not be sufficient to clean-up up a soil with a high metal contamination, does not mean that there is no potential for phytotechnology in the treatment and management of contaminated soils (Robinson *et al.*, 2009). Plants may in particular be used to promote the decomposition of biodegradable soil pollutants, which may occur after uptake within the plants or in the rhizosphere by reactions with root exudates and stimulation of microbial degradation (Pilon-

Smits, 2005). The greatest potential of phytotechnology in the treatment of contaminated soil is in applications where the plants can be used not only to control the risk situation associated with the pollution and gradually ameliorate the soil, but at the same time allow to make profitable use of the contaminated land, e.g. by the production of fibers, wood for construction, ornamental plants. Of course, this requires that contaminant concentrations in the products do not exceed legal tolerance limits. Combining risk control and gradual attenuation of the contamination with plant production for commercial use makes the phytomanagement of contaminated soil a particularly attractive treatment option where rather large areas of agricultural land are affected that would not be usable productively otherwise.

6 Conclusions and outlook

The strategy to monitor soil contamination by the NABO and to limit further soil contamination by the reduction of emissions from traffic, households and industry into the atmosphere and limitation of agricultural metal inputs was largely successful. There is still a legacy of contamination from past inputs, including a large number of small hotspots such as the more than 2000 shooting range sites all over the country contaminated primarily with lead and antimony. But with respect to new soil pollution by metals and persistent organic pollutants such as polyaromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB) or dioxins, the situation can be considered as being under control, and although there are still larger areas with lesser concentrations of these contaminants that have not been actively decontaminated, due to lack of urgency for treatment and lack of cost-effective clean-up methods, progress has been made in the clean-up of contamination hotspots such as brownfields and shooting ranges.

On the other hand, new compounds have become increasingly problematic as soil contaminants in the meantime, for example substances derived from use of medical and hygiene products. To stop the input of ever new chemicals from such sources via wastewater treatment, the application of sewage sludges was completely banned on agricultural land in Switzerland in 2005. However, inputs of pharmaceuticals used in livestock husbandry with manure continue to be a problem (Thiele-Bruhn, 2003), and a major debate currently rages on the use of pesticides (Chiaia-Hernandez *et al.*, 2017), which apart from water pollution, food chain poisoning and health risks for consumers of crop plant products now more and more also includes the issue of biodiversity loss above and below the soil surface.

The problem in dealing ever new chemicals is that regulations based on toxicological assessments will always be delayed, and the more compounds with highly novel properties appear on the market, the larger is the problem to determine their toxicity and thresholds for tolerable concentrations in soil. Thus, preventive regulatory approaches are needed that would allow to regulate novel chemicals already before conventional toxicological evaluation can be made, but is not too conservative either to avoid unnecessary blocking of technological progress.

Another problem is that the current approach of dealing with environmental pollution is too sectorial, as regulations relating to the same compound in different environmental compartments such as air, water, soil, waste disposal etc. were drawn up separately with insufficient coordination. It needs to be complemented by a comprehensive view looking at material cycles in the anthroposphere and the environment.

Despite its wide definition in the law, soil fertility does not embrace all important aspects of soil as a natural resource. Soil protection must include the sustainable management of soils to preserve, restore and improve the entirety of essential ecological soil functions and ecosystems services for society. To achieve this goal a better coordination between government agencies involved in the development of land use and soil management is needed, in particular between spatial planning and soil protection (Greiner *et al.*, 2018), and such coordination requires a detailed and comprehensive soil information system (SIS) allowing to feed data on soil potentials and vulnerabilities into spatial planning processes as early on as possible.

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