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Health risk assessment for sewage sludge applied to land in France

ABSTRACT

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Version	Date	Opinions taken into account
0	04 November 2005	Opinion from a group of experts Opinion from involved professionals
1	15 October 2007	Opinion from involved ministries: ministry of agriculture, ministry of public health, ministry of environment Opinion from OPERSEI (observatory of practices in health risks assessment for impact studies) Opinion from involved professionals

Health risk assessment for sewage sludge applied to land in France

In France, municipal and industrial sludges from wastewater treatment works are regarded as waste within the existing regulation (French law n°75-633 of July 15, 1975). The fertilizing properties of these wastes have been recognized for many years and their application on agricultural lands for more than 30 years in France is considered as an environmental and economical sustainable practice. Because of the presence of chemical contaminants and pathogens in sludge, precaution measures are taken for the management of land spreading operation to guarantee food safety and the preservation of soils and other environmental compartments. They are framed by the French law n°92-3 of January 3, 1992 known as law on water and law n°76-663 of July 19, 1976 related to the classified installations for the environmental protection, and by a European directive on sewage sludge (currently under review). In France, land spreading of municipal and industrial sludge produced by a treatment work under the authorization regulation has to fulfill a study relative to the human health impact. However no guideline to carry out such health risk assessment is available so far.

The objectives of the present study were the development of methodologies to assess both chemical and microbiological risks to human health. For the chemical part, the methodology was developed and tested on one real case study including land spreading of urban sludges. For the microbial part, as there are no limit values for pathogen concentrations (except for sludges that undergo treatments to reduce *Salmonella*, Enterovirus and helminth eggs), a feasibility study based on a literature review was undertaken.

1 Chemical health risk assessment

The chemical health risk assessment methodology was developed with respect of the general risk assessment principles defined by US-EPA and already used in other French methodologies dedicated to other environmental media (contaminated soils for instance).

In this specific case, risk assessment has to take into account:

- the background levels in soils and in food for each implied substance;
- the duration of sludge landspreading;
- the sludge spreading frequency on a same plot.

The description of the methodology set up can be done according to the determination of site characteristics followed by the four steps mentioned below:

- evaluation of toxic effects for the selected substances;
- selection of toxicological reference values;
- exposure evaluation;
- risk quantification.

The methodology developed here is based on a site-specific approach. The risk assessor has first to evaluate the site properties and technical methods of spreading which will lead to an accurate risk quantification. Among these characteristics, sludge composition (type of pollutant and concentrations), soils

characteristics (texture, pH…), agricultural practices (cultures and spatial and temporal distribution, sludge application…) have to be properly known to define which substances will be selected during the quantification step. It was defined that **at least** each substance mentioned in the regulation should be selected to assess potential risks of sludge land spreading, these substances currently being in the French legislation heavy metals (cadmium, chromium, copper, mercury, nickel, selenium, lead and zinc), polycyclic aromatic hydrocarbons (fluoranthene, benzo[b]fluoranthene, benzo[a]pyrene) and polychloro-bi-phenyls. Critical issue of this first step is the definition of a conceptual scheme defining substances, exposure pathways and receptors to be considered for the risk quantification procedure.

Toxic impacts have to be described for each effect of the studied substance (threshold or non-threshold effects). A thorough description of the different organs on which substances have an effect has to be done. When available, quantitative data about the effects of the substances on human being will be selected among data available into the international toxicological databases. These toxicological reference values (TRV) will be used for risk quantification.

The evaluation of the dose of exposure (ED) for each receptor and each exposure pathway requires the estimation of the substance concentration in the soil on which sludge is spread (source of contamination), the values of parameters needed to estimate the transfer of substances to human being (through either direct or indirect contact) and the values of parameters concerning daily food ingestion, space and exposure time for each receptor.

Receptors and exposure pathways that have to be considered by the risk assessor are described below.

Chemical assessment : receptors and exposure pathways.

	Farmers	Inhabitants	General Population
Direct Contact			
Soil ingestion	x	x	
Dust inhalation	x	x	
Indirect Contact			
Agricultural products consumption	x	x	x

In predictive scenarios, concentration of each substance has to be calculated theoretically considering soil background levels and sludge dilution in a mass of agricultural soil. This mass depends on soil density and depth of ploughing. The exposure to general food (which is not concerned by sludge land spreading) is also estimated in order to compare these different risk levels.

This final step allows to calculate, for threshold and non-threshold effects of each substance, the risk for each identified exposure pathway. Concerning the threshold effects, the risk value for each health effect is obtained according to equation 1:

$$RV_{threshold\ effect} = ED / TRV \quad (1)$$

whereas concerning the non-threshold effects, the risk value for each receptor is obtained according to equation 2:

$$RV_{\text{non-threshold effect}} = ED \times TRV \quad (2)$$

Analysis of these values by the risk assessors has to be done concomitantly to the examination of uncertainties related to the methodology and phenomena taken into account when modeling the fate of pollutants from soils containing sludge to Man. It is usually considered that risks are acceptable when $RV_{\text{threshold effect}} < 1$. Concerning the $RV_{\text{non-threshold effet,}}$ the acceptable value has to be set up by the regulator.

The methodology described before was applied to assess the chemical health risks on one French site dedicated to the spreading of sewage sludge, for which lands were entirely dedicated to cereals cultivation. For this site and whatever the receptors, risks values specifically due to sludge spreading were below 1 for the threshold-effect and below 10^{-5} for the non-threshold effects showing that, according to our methodology and under the different assumptions made for the calculation, the spreading of sewage sludge on agricultural lands was an acceptable practice. If we consider the cumulative exposure of general food and of food implied in sludge spreading, the risk value for the threshold effects on the kidney for the children is slightly more than 1, but the consumption of plants harvested on amended soils contributes to only 0,002% of this value. In all the cases, the more significant risks were associated with the plant consumption coming from non amended soils.

2 Microbial health risk assessment

The objective of this study was to estimate the microbial risks to humans linked with pathogens in municipal or industrial sludge spread on land in the French environmental regulation context.

Since the first French report on microbial health risks for sewage sludge in 1998, French research studies and thesis were carried out. The first objective of this work was the analysis of the current knowledge on all the steps of the risk assessment approach. The second objective was the evaluation of the feasibility to implement a quantitative assessment of the risks of infection to humans.

Reports of this type have been published in particular in the United Kingdom and the United States, so it appeared interesting to develop a case study based on data adapted to the French context. Taking into account the relevance to apply this exercise within the framework of national studies resulted in the setting of qualitative guidelines.

A literature review provided current available data on loads of pathogens in sludge, their sensitivity to sludge treatments and to storage, their survival in soil and their transport to environmental media (soil, water and air) after spreading, data on other sources of pathogens in the agricultural environment, epidemiological data (linked to direct exposure to sludge, wastewater and sludge composts as well as a synthesis on environmental waterborne outbreaks in France) and their health outcomes. This review also allowed to highlight main gaps of knowledge.

During more than 30 years of practice in France, no environmental epidemic outbreak linked with the spreading of sludge was detected. We found a few epidemiological studies conducted specifically for sludge exposure in our literature review. The examination of the whole available epidemiological data in France indicated that ingestion of contaminated drinking water without any proven link with land spreading of sludge is to the present day the only way of exposure blamed in the waterborne outbreaks of environmental origin.

For ten years, French studies collected data on detection and quantification of certain pathogenic agents (helminth eggs, *Giardia spp*. cysts, *Salmonella*, Enterovirus, VHA, verotoxic *E. coli*, *Listeria spp*.) in sewage sludge. Helminth *Ascaris sp*. has practically disappeared in humans and pigs in metropolitan France because of hygienic rules and industrial breeding. *Taenia saginata* probably represents the last principal parasitic threat for human and animal health since it is practically found in all the sludges analyzed under moderate climates. The review also shows that contamination of raw municipal sludge is quasi systematic. Some pathogens are little studied (*Cryptosporidium sp.*, other protozoa like *Balantidium* sp., *Campylobacter sp*., *Yersinia spp*., *Vibrio spp*., shigatoxins producing *E coli*...) or are not studied at all in sludges (Adenovirus, Calicivirus, Astrovirus, mycobacteria, microsporidia...). Only two studies on the contamination of raw French slaughterhouses sludge were found.

In France, there are some data on the contamination of treated municipal sludge (Enterovirus, *Listeria sp*., *Giardia* cysts, helminths eggs) but not on those of slaughterhouses or dairies waste water treatment works. All in all, the advanced treatments for the reduction of pathogens recommended by the European Community in 2001 are: composting, thermal drying, thermophilic digestion, followed heat treatment followed by digestion and liming.

The French standardized methods for the analysis of pathogens in sludge are only available for helminth eggs, *Salmonella* and soon for the Enterovirus. The European project Horizontal is intended to supplement currently available tools for sampling and analysis for the sludge matrix.

Many factors influence the survival of pathogens in the environment. Most of the time, survival is decreasing within 2 months because of the adverse conditions (desiccation, temperature, natural competition) in the environmental media.

The pathogens of small size (virus, bacteria and some protozoa) can be found in bioaerosols formed by the spreading with spray tanker or spray irrigation application of liquid sludge under windy conditions.

Water constitutes the main pathway of pathogens dissemination in the environment. However, in France, contamination of water is reduced by the respect of the regulation (buffer zones between spreading area and sensitive uses). Moreover, taking into account the French regulated times of spreading, it is unlikely to find pathogens on plants grown on agricultural soils spread with sludge. The role of animals grazing on those sites in the transmission of pathogens to man is reduced.

According to our findings, the principal needs of data concern:

- the determination of the species of the biological agents in sludge (salmonella, *campylobacter spp*., *cryptosporidium sp.* ...) as deeper knowledge would make it possible to identify the human, animal, environmental origin of the pathogens,

- the presence, quantification and virulence of pathogens in raw and treated municipal sludge (endotoxins, *Staphylococcus aureus*, *Vibrio spp*, viruses (rotavirus, calicivirus, adenovirus...), pathogenic *E coli*, *Pseudomonas aeruginosa Cryptosporidium spp*., mycobacteria, microsporidia...) and in industrial sludge (*Pseudomonas spp., Listeria monocytogenes*, *Campylobacter spp*., *Salmonella*),
- the determination of presence and ecology of *Legionella* and its methods of detection in sludge,
- the construction of a data base on the survival and transport of pathogens (and in particular of viruses) in the environment (soil and plants),
- the human exposure to bioaerosols and composts of sludge at the time of spreading on land.

Despite of many uncertainties linked to the state of knowledge, a preliminary quantitative risk assessment case study was developed for liquid raw sludge in order to identify the critical points of the process and to judge its relevance within the national context of health impact studies.

From a list of principal pathogens of concern in sewage sludge established by ADEME and EPA in 1999, Enterovirus, *Salmonella*, *E coli* O157 :H7 and *Cryptosporidium parvum* were selected on two criteria: existing data on load of pathogen in sludge or sewage water in France and on dose-response curves by ingestion.

The conceptual model was based on the simplified source-pathway-receptor event tree approach. Two receptors and three exposure pathways were considered: farmers plowing and ingesting dust from soil receiving sludge and nearby populations consuming their own vegetable products contaminated either by biological aerosols from the land receiving sludge either by erosion of amended soil. Many worst case assumptions were considered based on experts' judgment. The main assumptions are presented below.

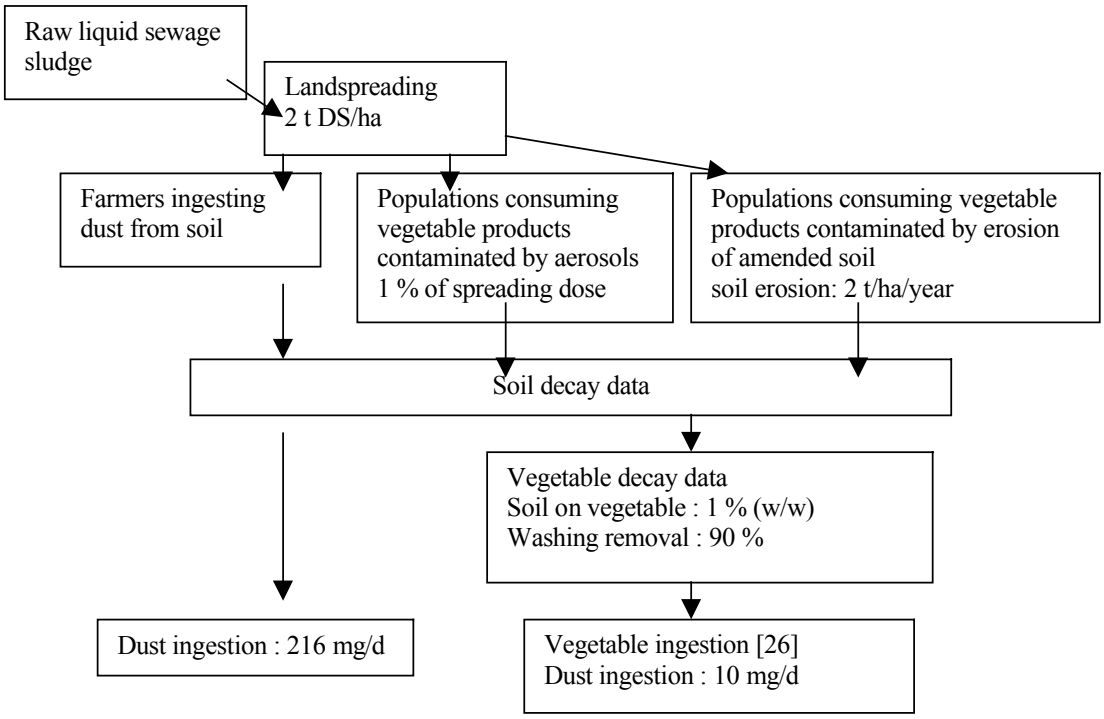
Under main worst case assumptions and in the current state of knowledge, preliminary results for the liquid raw sludge spreading showed that: calculated exposures for both receptors are very weak; whatever pathogen is considered, the risks to have at least one infection over the exposure time is in decreasing order:

population/bioaerosol > farmer > population/erosion;

whatever receptor is considered, the risks to have at least one infection over the exposure time is in decreasing order:

Enterovirus > *Salmonella* > *Cryptosporidium parvum* > *E coli* O157: H7.

This preliminary quantitative risk assessment was developed on a great number of working assumptions surrounded by uncertainty. Indeed, in the absence of sufficient data, values considered as realistic or worst case were used following a consensus of experts.



Microbial assessment : Exposure event tree

The main sources of uncertainty in the model are:

- the estimation of the pathogen load in sludge that is directly related to the natural heterogeneity and to uncertainties of microbiological methods of analysis,
- the dose-responses relations that are rare in the literature, mostly available for ingestion and not built for the sludge matrix, in addition the existence of an acquired immunity or the genetic specificity of certain individuals are not taken into account because it is not easily quantifiable,
- the modeling of pathogens decay in soil environment and vegetables is very simplified and there is currently no experimental evidence to support the pathogens concentration results,
- the exposure scenarios used for both receptors correspond to the worst case situations (for example use of an open tractor for the farmer which increases significantly the quantity of dust ingested, and for the residents, use of uncertain modeling of bioaerosols deposition because of the lack of experimental data) which are not representative of the "normal" conditions of spreading in France,
- an important phenomenon (losses in the environment at the time of the rain) was not taken into account.

The feasibility study enabled us to propose guidelines based on a qualitative analysis of the microbial risks and control measures. The analysis can be carried out according to the decisional tree that includes the data needed to describe sludge spread to land, the exposed populations and the preventive measures. Measures of risk reduction are based on solutions proposed by the French regulation: either a reduction of the sludge pathogens load (hygienized sludges) or a reduction of the human exposures (for other sludges).