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In situ groundwater and sediment bioremediation: barriers and perspectives at European contaminated sites

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This paper contains a critical examination of the current application of environmental biotechnologies in the field of bioremediation of contaminated groundwater and sediments. Based on analysis of conventional technologies applied in several European Countries and in the US, scientific, technical and administrative barriers and constraints which still need to be overcome for an improved exploitation of bioremediation are discussed. From this general survey, it is evident that *in situ* bioremediation is a highly promising and cost-effective technology for remediation of contaminated soil, groundwater and sediments. The wide metabolic diversity of microorganisms makes it applicable to an ever-increasing number of contaminants and contamination scenarios. On the other hand, *in situ* bioremediation is highly knowledge-intensive and its application requires a thorough understanding of the geochemistry, hydrogeology, microbiology and ecology of contaminated soils, groundwater and sediments, under both natural and engineered conditions. Hence, its potential still remains partially unexploited, largely because of a lack of general consensus and public concerns regarding the lack of effectiveness and control, poor reliability, and possible occurrence of side effects, for example accumulation of toxic metabolites and pathogens. Basic, applied and pre-normative research are all needed to overcome these barriers and make *in situ* bioremediation more reliable, robust and acceptable to the public, as well as economically more competitive. Research efforts should not be restricted to a deeper understanding of relevant microbial reactions, but also include their interactions with the large array of other relevant phenomena, as a function of the truly variable site-specific conditions. There is a need for a further development and application of advanced biomolecular tools for site investigation, as well as of advanced metabolic and kinetic modelling tools. These would allow a quicker evaluation of the bioremediation potential of a site, and in turn a preliminary assessment of the technical feasibility of the chosen

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bioprocess which could replace or at least reduce the need for time-consuming and expensive field tests. At the same time, field tests will probably remain unavoidable for a detailed design of full scale remedial actions and the above reported tools will in any event be useful for a better design and a more reliable operation.

Introduction

Background

After more than two centuries since the start of industrialisation and due to the increased use of xenobiotics and hazardous materials in many production processes, Europe is now facing the problem of contamination of soil, groundwater and sediments. More recently, the environment policies adopted on waste reduction, water protection, and environmental liability are enforcing a strong array for protection of environmental resources against future risks. In particular, the European Directive on environmental liability [1] established a common liability framework across the EU, to be applied when soil and groundwater contamination creates a significant risk for human health and/or damage of environmental resources. Unfortunately, the common liability regime does not apply to historical contamination or to damage which occurred prior to its entry into force, which still represent most frequent cases of site remediation.

As for establishing a more specific framework for protection of soil, the European Commission also adopted the communication 'Towards a Thematic Strategy on Soil Protection' [2] and a Proposal for a Directive of the European Parliament and of the Council is still under discussion [3]. In this context, the number of potentially contaminated sites and the number of sites actually contaminated and needing remediation have been estimated at 3.5 and 0.5 million, respectively, has been estimated at 0.5 million. Moreover, annual costs of soil contamination have been estimated in the range €2.4–17.3 billion [3].

According to the Proposal, Member States will have to perform a preliminary survey of potentially contaminated sites, to be based on a pre-established screening list of potentially dangerous industrial activities, which will produce a priority list of sites to be further investigated to determine which sites are actually contaminated and need remediation. The costs for preliminary survey are estimated at about €51 million per year (at the European level), followed by on-site investigations (up to €240 million yearly), to finally conclude whether there is a significant risk to the human health or environment. In the perspective of such an enormous effort, new approaches to site remediation should be developed and implemented to increase the 'sustainability' of remediation, both in the environmental and economic sense. Indeed, a European survey (EURODEMO, 2006) confirmed that the Dig and Dump (D&D) and Pump & Treat (P&T) remain the most common approaches to soil and groundwater remediation, respectively [4].

On the contrary, we should move forward from such waste- and energy-intensive approaches, towards more sustainable remediation approaches, to:

- recover natural functions and potential uses of environmental resources to be remediated (e.g. quantitative and qualitative preservation of groundwater resources);
- minimise extraction of water and production of wastes to be disposed of;
- favour the continued economic use of the site during remediation.

Inventory of remediation technologies at contaminated sites in Europe

A single comprehensive source of remediation activity information does not exist in Europe. The desired information has to be compiled from different sources, bearing in mind that quantitative data are not always mutually comparable. Hence, the country-wise display of projects and technologies is often unrepresentative. In addition, the available information is often incomplete, as only a portion of the existing remediation projects or technological applications are provided. Hence, the numbers presented in the text below cannot claim to be complete, representative, or comparable.

Site remediation in Italy

In Italy, there are presently 38 sites whose remediation is considered to be of national interest, based on their environmental relevance (National Programme for Site Remediation). Any remediation action at these sites has to be formally approved by the Ministry of Environment and a national financial support was made available mainly for emergency containment of contamination. Many sites from the National Programme are so called 'megasites', including seven that are larger than 10,000 hectares (ha) and many sites larger than 100 ha. These sites include all main industrial fields and accordingly a wide range of contaminants is present in soil, subsoil and groundwater thereof. Many sites are located in coastal areas, including harbours and lagoons; hence, the related pollution also often extends to shallow sediments.

Moreover, it has been estimated that about 15,000 contaminated sites of minor relevance will have to be remediated or at least monitored, at a cost of about €25–30 billion over the next 15 years.

When a groundwater is contaminated, the Italian national rule requires that emergency safety actions are taken, so as to avoid the spreading of the contaminated plume and the deterioration of nearby connected water bodies. Due to their rapid viability, emergency actions are usually achieved by passive (cut-off walls and drainage trenches) or dynamic barriers (hydraulic barriers) and their realisation brings with it the need for 'pump-and-treat' (P&T). Moreover, the large use of P&T systems is due to their ease of design and control, being based on adduction to a treatment plant and a final control of a localised effluent. A recent study concerning 17 National Sites in Italy, estimated an investment cost of €604 M for P&T systems, based on either hydraulic containment or impermeable walls and drains. 41% of the investment cost was for new and *ad hoc* designed 'groundwater' treatment plants for which the average unit investment cost was around €50,000/(mc/h) [5]. The estimated overall flow rate was 45 Mm^3/y (about 500,000 inhabitant equivalents) with an average operation cost of €2.4/m^3. The high operation cost was mostly due to the most

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