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Health risk assessment linked to filling coastal quarries with treated dredged seaport sediments

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HIGHLIGHTS

- The release of polluted dredged seaport sediments into the sea must be avoided.
- Their use after treatment for the filling-up of quarries is proposed by managers.
- An original health risk assessment methodology was created to validate this option.
- It includes the use of a lysimeter and a georadar for the exposure assessment stage.
- The example studied concludes to a health risk linked to arsenic in the groundwater.

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ABSTRACT

Dredged seaport sediments raise complex management problems since it is no longer possible to discharge them into the sea. Traditional waste treatments are poorly adapted for these materials in terms of absorbable volumes and cost. In this context, filling quarries with treated sediments appears interesting but its safety regarding human health must be demonstrated. To achieve this, a specific methodology for assessing health risks has been developed and tested on three seaport sediments. This methodology includes the development of a conceptual model of the global scenario studied and the definition of specific protocols for each of its major steps. The approach proposed includes in particular the use of metrological and experimental tools that are new in this context: (i) an experimental lysimeter for characterizing the deposit emissions, and (ii) a geological radar for identifying potential preferential pathways between the sediment deposit and the groundwater. The application of this approach on the three sediments tested for the scenario studied showed the absence of health risk associated with the consumption of groundwater for substances having a “threshold effect” (risk quotient <1), and an acceptable risk for substances having a “non-threshold effect”, with the notable exception of arsenic (individual risk equal to 3.10^{-6}).

1. Introduction

Seaports are regularly confronted with the need to dredge their sediments. In France, seaport dredging generates from 25 to 40 million tons of material annually which has to be managed afterwards. Most of these sediments are uncontaminated and are therefore discharged into the sea as they are. The authorization of these discharges depends on the regulation in force in the country which is concerned. In the case of France, this authorization is given based on 3 principal criteria: the sediment volume, the proximity or not to an oyster farming area, and the concentration level in pollutants (MEEDDAT, 2008; IFREMER, 2001). If the discharge into the sea is not authorized, the contaminated sediments must be treated on land, which poses complex management problems. Indeed, traditional waste treatment methods (landfilling, incineration, physico-chemical centers, etc.) are not suitable, either economically or in terms of absorbable volumes, for storing this new source of contaminated materials. Based on this observation, the “SEDiGEST” national research project (SEDIGEST, 2011) focused on filling coastal quarries with dredged seaport sediments, an attractive alternative because it also allows solving the nuisance linked to the presence on the coast of a large number of quarries which disfigure the landscape. However, the safety of this solution regarding local ecosystems and human health must be demonstrated. The risk assessment on ecosystems has been the subject of a first paper (Perrodin et al., 2012). The present article concerns the development of a health risk assessment methodology, usable when there is a possibility of pollution of the groundwater situated beneath the quarry, if this groundwater is used

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to produce drinking water. This development requires taking into account the major bio-physico-chemical processes occurring at the storage site. The physico-chemical composition of dredged sediments from seaports is now well known, determined by numerous studies performed in different countries (massive presence of chlorides, presence of heavy metals, PAHs, TBT, etc.) (Alebic-Juretic, 2011; Bhosle et al., 2006; Blanca, 2008; Colacicco et al., 2010; Gschwend and Hites, 1981; Langston et al., 1987; Lepland et al., 2010; Romano et al., 2004; Saeki et al., 2007; Simpson et al., 1996), but much remains unknown about their behavior after their deposition on soil, where they are subject to oxidation and rainwater (Chatain et al., 2009; Saeki et al., 2007). Among these unknowns, mention may be made here of: (i) the role played by chlorides in the cohesion of the sediment matrix and in the solubility of mineral and organic pollutants in the long term; (ii) the role of oxidation conditions when the sediments are stored on land, and the resulting changes in the chemical form of the metals contained in the sediments (for example, cadmium and zinc, which are mainly in the form CdS and ZnS in marine sediments, are gradually transformed into cadmium and zinc carbonates, oxides, sulfates and phosphates), with completely different solubilities; and (iii) the behavior of percolates between the deposit basement and the groundwater, particularly in the case of heterogeneous soils, with potentially preferential pathways.

In this paper, we first present the specific health risk assessment methodology established to assess the health risks linked to filling coastal quarries with dredged marine sediments. Then, we present the results of the application of this methodology to three dredged sediments taken from three seaports located in the south (Mediterranean Sea) and in the west (Atlantic Ocean) of France. The analysis of obtained results provides some initial information on the health risks connected with this type of deposit. It equally enables to make some proposals for the future improvement of the methodology.

Note: Other approaches exist for the assessment of health risks associated with contaminated marine sediments (Revis et al., 1989; Shao et al., 2011; Yi et al., 2011). However, these approaches concern the health risk assessment of sediments in ports or during discharge into the sea, and are not adapted to the scenario studied here. In particular, in these approaches the primary exposure pathway is most often the consumption of contaminated fish, while in our work it is the consumption of polluted groundwater, downstream of an inland sediment deposit.

2. Materials and methods

2.1. Global approach

In 1983, the National Research Council (NRC) proposed a methodological approach to Health Risk Assessment (HRA) in four stages (NRC, 1983): hazard identification, dose–response assessment, exposure assessment and risk assessment (Fig. 1). The approach, now universally recognized, was then included in the methodological guide for the US-EPA HRA related to contaminated sites (US-EPA, 1989).

In France, the INERIS has developed a methodological guide for industrial HRA (INERIS, 2003) based on the approach of the NRC, while the Institute of Health Surveillance (INVS) has developed a guide for the analysis of the health component of the impact study assessment, including the following steps: (i) hazard identification, (ii) definition of dose–response relationships, (iii) assessment of population exposure, and (iv) risk characterization (INVS, 2000). Other countries have developed their own approaches, but the four major steps remain the same (AIEH, 2002; CMEP, 2011; EC, 1995; Health-Canada, 2004; HSE, 2011; MSSS, 2002; RIVM, 2013).

In this article, we have implemented the four stages of NRC for the HRA related to the use of groundwater for a typical scenario established for the purposes of the study.

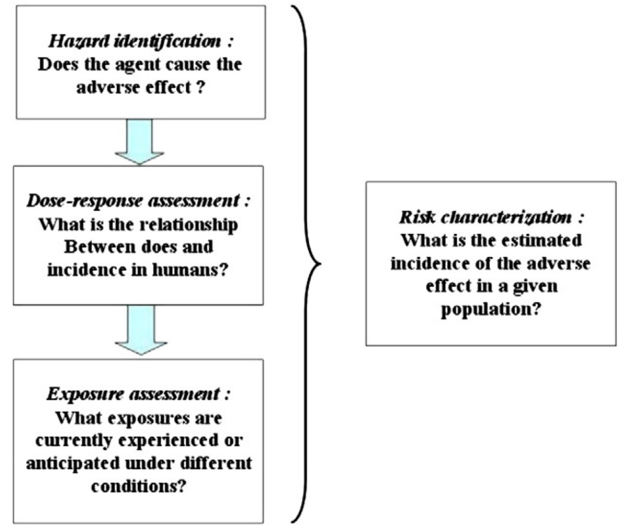

Fig. 1. Methodology of health risk assessment of the NRC (1983).

2.2. Description of the scenario

In order to visualize the fate of pollutants from the source of emission to the "target", i.e. the component that has to be preserved, a detailed diagram of the scenario is shown in Fig. 2.

Although this article deals only with the health risks associated with the use of the groundwater, this diagram incorporates the visualization of all the targets to be protected and all the potential transfers, in order to provide an overview of the context in which the present study was performed. In addition, a comparative analysis of health risk and ecological risk published elsewhere for the same scenario (Perrodin et al., 2012) is given in the discussion further on.

The spatial and numerical data were defined arbitrarily for the needs of the study (Table 1), although with care being taken to remain as close as possible to field conditions.

Lastly, the flows of pollutants between the source of pollution and the targets to be preserved, and the dilution factors resulting from the digital data above, were integrated in a conceptual model summarizing the approach selected (Fig. 3).

2.3. Hazard identification

Regarding source S1, three samples of treated maritime sediments were selected to perform the assessment. The three sediments were taken from a site on the Atlantic seaboard (Port of Guilvinec, France) and from a site on the Mediterranean seaboard (Port of Toulon, France). These sediments were: (i) sediment from the port of Toulon, dried and aired for 4 months (sediment 1), (ii) fine fraction of the sediment from the port of Toulon, dried and aired for 4 months (sediment 2), and (iii) sediment from the port of Guilvinec, amended with lime, cement treated and crushed (sediment 3).

The detailed analysis of the three sediments is provided in our publication on the ecological risks (Perrodin et al., 2012). The main source of emission of pollutants to groundwater (Target C2) is the percolation of rainwater through the deposit. Table 2 presents the substances used as "risk tracers" to human health, in the light of current knowledge on seaport sediments and their potential toxicity to humans.

2.4. Dose–response relationships

This step involves the search for Toxicity Reference Values (TRV), for oral use (consumption of water from the aquifer), and for substances identified as hazardous in the dredged sediments. It was carried out for substances with a "threshold effect" and for substances with a