# Risk Assessment Applied to the Recovery of Recycled Aggregates for Quarry Backfilling Case Study in the Province of Brescia

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## Introduction

As of today in Italy, environmental assessment related to waste recovery is exclusively based on the use of the leaching test (D.M. 186/2006 [1]), and there is no existing methodology for risk assessment related to the recovery of these materials through Risk Analysis that takes into account the usage scenario and site-specific conditions. This study exemplifies the modelling of leaching pollutants present in a quarry backfilling consisting of Recycled Aggregates (RA) and, based on its geometry and the characteristics of the surrounding environment, estimates the expected concentrations in the groundwater beneath. For the study, concentrations in the leachate were evaluated using data from leaching tests conducted on recycled aggregates produced by the company throughout the year 2022 according to UNI-EN 12457-2 [2]. The potential impact on the groundwater resulting from their leaching was assessed considering the Groundwater Contamination Threshold Concentrations defined by Legislative Decree 152/06 [3] as reference limits.

## Materials and methods

The study was conducted following the approach outlined by the Italian Environmental Agency for health and environmental risk assessment of contaminated sites (APAT, 2008) [4]. The attenuation of contaminant concentration due to transport from the backfill to the groundwater is determined by the leaching factor (LF), a parameter that accounts for water infiltration into the unsaturated soil layer (SAM), that considers the path the pollutant takes to reach the water table, and dilution in the aquifer (LDF), that takes into account the dilution that the contaminant undergoes once it reaches the aquifer, during the transition from unsaturated soil to saturated soil. Figure 1 represents the schematization of the transport mechanism in the case study.

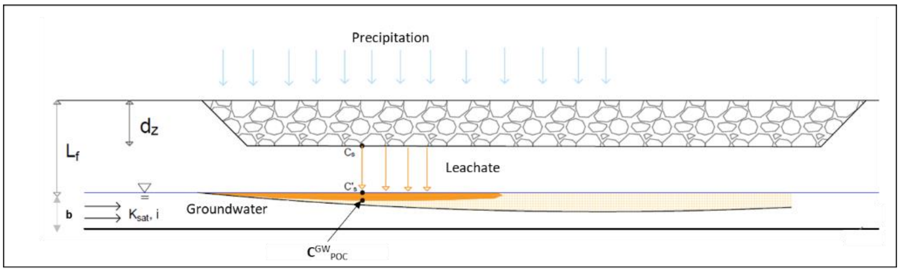


**Figure 1.** Schematization of the transport mechanism

For the application of the model, the geometric characteristics of the intervention (backfill thickness: $d_z$=17.75m; backfill extension in the direction of the aquifer flow: W=159m) and site-specific characteristics (aquifer depth from top of the source: $L_f$= 25.5m; hydraulic gradient: i=0.0009; hydraulic conductivity: k=8.25E-05 m/s; aquifer thickness: b=10m; annual cumulative precipitation: P=997mm/y) were collected. Based on the pollutant concentrations found in 183 eluates obtained from the leaching test (UNI EN 12457:2 [2]), the 80th percentile and Upper Confidential Limit 95% (UCL 95%) were calculated and reported in table 1 ($C_s$).

The expected concentrations in the groundwater ($C_{gw}$) along the vertical axis relative to the intervention were estimated using the predictive model provided by APAT (2008) [4].

To assess the impact on the groundwater due to leaching, the threshold contamination concentrations for groundwater ($CSC_{GW}$) defined by Legislative Decree 152/2006 Part IV, Title V, Annex 5, Table 2 [3], and for parameters for which there was no predefined value, were considered other reference limits.

The risk was calculated for each considered pollutant as the ratio between the expected concentration in the groundwater and the CSC. The risk is considered acceptable when the observed value is less than 1.

## Results

The result related to the evaluation of the environmental risk assessment for groundwater obtained with the study are reported in table 1.

**Table 1.** Risk calculated

| Parameter | U.o.M | $CSC_{GW}$ | $C_s$ | $C^{GW}_{poc}$ | Risk $R_{GW}$ | $C_s$ | $C^{GW}_{poc}$ | Risk $R_{GW}$ |
|---|---|---|---|---|---|---|---|---|
| | | | [80° percentile] | | | [UCL 95%] | | |
| $NO_3^-$ | mg/l | 50 | 18.16 | 6.81 | 0,14 | 13.82 | 5.18 | 0.10 |
| $F^-$ | mg/l | 1.5 | 0.51 | 0.19 | 0,13 | 0.37 | 0.14 | 0.09 |
| $Cl^-$ | mg/l | 250 | 10.00 | 3.75 | 0,02 | 11.23 | 4.21 | 0.02 |
| $SO_4^{2-}$ | mg/l | 250 | 80.56 | 30.20 | 0,12 | 62.21 | 23.33 | 0.09 |
| $CN^-$ | µg/l | 50 | 10.00 | 3.75 | 0,08 | 10.00 | 3.75 | 0.08 |
| Ba | mg/l | 0.7 | 0.10 | 0.04 | 0,38 | 0.12 | 0.05 | 0.06 |
| Cu | mg/l | 1 | 0.04 | 0.01 | 0,01 | 0.03 | 0.01 | 0.01 |
| Zn | mg/l | 3 | 0.10 | 0.04 | 0,01 | 0.13 | 0.05 | 0.02 |
| Be | µg/l | 4 | 1.00 | 0.37 | 0,09 | 1.00 | 0.38 | 0.09 |
| Co | µg/l | 50 | 5.00 | 1.87 | 0,04 | 5.00 | 1.88 | 0.04 |
| Ni | µg/l | 20 | 5.70 | 2.14 | 0,11 | 8.57 | 3.21 | 0.16 |
| V | µg/l | 50 | 31.90 | 11.96 | 0,24 | 22.92 | 8.60 | 0.17 |
| As | µg/l | 10 | 7.20 | 2.70 | 0,27 | 11.97 | 4.49 | 0.45 |
| Cd | µg/l | 5 | 0.50 | 0.19 | 0,04 | 0.52 | 0.20 | 0.04 |
| Cr | µg/l | 50 | 43.76 | 16.40 | 0,33 | 32.88 | 12.33 | 0.25 |
| Pb | µg/l | 10 | 5.90 | 2.21 | 0,22 | 5.77 | 2.16 | 0.22 |
| Se | µg/l | 10 | 5.32 | 1.99 | 0,20 | 3.23 | 1.21 | 0.12 |
| Hg | µg/l | 1 | 0.50 | 0.19 | 0,19 | 0.52 | 0.20 | 0.20 |

The concentrations calculated at the 80th percentile is higher than the 95% UCL, hence providing a higher safety margin. It is observed that, in the hypothesized site-specific situation, the estimated concentrations in the aquifer beneath the fill, resulting from the leaching of recycled aggregates, comply with the concentrations defined by Annex 3 to D.M. 186/06 [1], and are lower than the CSC provided for by Legislative Decree 152/06 [3] for all pollutants and consequently, the risk is acceptable. Barium and chromium were the parameters with the highest risk calculated.

**Concluding Remarks**

A risk-based approach should be pursued when reusing waste or secondary raw materials in scenarios that can impact the environment and human health. The risk assessment procedure is widely applied to landfills and contaminated sites. In recent years, the risk assessment methodology has also been applied to waste reuse in unbound applications.

In the considered case study, the risk has been found acceptable (with $R_{GW} < 1$) using the eluate concentrations at the 80th percentile and UCL 95%. It should also be taken into consideration that concentrations data are obtained from leaching tests with a liquid-to-solid ratio (L/S) of 10 l/kg, a ratio that is not representative in the context of waste recovery and is more characteristic for assessing leaching process in landfills; furthermore, leaching test used considers material with particle size lower than 4 mm, which rarely corresponds to the physical characteristics of the material used for recovery operations. In this specific case, the recovered material indeed has a particle size ranging from 0 to 90 mm. To overcome these limitations, different leaching tests could be used that employ a different liquid-to-solid ratio (e.g., EN 12457-1: L/S = 2 l/kg [4]), column percolation tests or other type of leaching tests in situ that better simulate the real conditions.

**Reference**


1. Ministro Dell'ambiente E Della Tutela Del Territorio. Decreto Ministeriale n. 186/2006. Regolamento Recante Modifiche Al Decreto Ministeriale 5 Febbraio 1998. Gazzetta ufficiale 2006, n.115.

2. EN 12457 - Characterization Of Waste - Leaching - Compliance test for leaching of granular waste materials and sludges - Part 1: One stage batch test at a liquid to solid ratio of 2 l/kg for materials with particle size below 10 mm (without or with size reduction); - Part 2: One stage batch test at a liquid to solid ratio of 10 l/kg for materials with particle size below 10 mm (without or with size reduction).

3.DECRETO LEGISLATIVO 3 aprile 2006, n. 152. Norme in materia ambientale. Gazzetta ufficiale 2006, n.88.

4. APAT (2008). Criteri metodologici per l'applicazione dell'analisi assoluta di rischio ai siti contaminati, Rev.2.