Groundwater contamination risk assessment based on advection-dispersion equation

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Abstract. The consequences of contaminated groundwater can seriously affect sustainable development; present and future generations being seriously affected by inadequate drinking water quality, loss of water supply, degraded surface water systems, high remediation costs, more expenses for other water supplies, and likely health issues. Therefore, an effective way to protect groundwater resources is by assessing the risk of groundwater contamination. An assessment of groundwater pollution should be performed to determine the level of risk posed by soil and groundwater contamination and establish if remediation strategies are required to protect controlled waters from site-derived contamination. Furthermore, if remediation is deemed necessary, site-specific remedial targets should be derived. A case study is presented, where a Conceptual Site Model was derived based on a "Source-Pathway-Receptor" exposure mechanism using historical information. Primary sources of contamination at the site are residual contamination within the soil and groundwater, and samples were collected from the site and tested in the laboratory; the concentration of water samples was compared to Romanian Drinking Water Standards. The following potential migration pathways have been identified: Leaching from soil and Migration of contaminated groundwater. The Detailed Quantitative Risk Assessment (DQRA) has modelled the leaching of contaminants from the site via infiltration and vertical migration to the groundwater and subsequent lateral groundwater migration, with dilution and attenuation process active, to the compliance point, using Ogata-Banks equation. The results of this assessment indicate that the concentration of contaminants does not represent a significant risk to controlled waters.

1. Introduction
Numerous countries around the globe are facing groundwater depletion and contamination. In many aquifers have been noticed that the groundwater levels have fallen drastically in recent times. It is estimated that about one-third of the world's largest aquifer systems are in distress.

Different stressors can deplete aquifers: from changes in precipitation and snowmelt patterns, followed by withdrawal of groundwater for drinking, irrigation, and various human uses, or rigid concrete overlays which prevent precipitation from restoring groundwater. Humankind should consider that some deep aquifers may take thousands of years to replenish.

Apart from the stressor heavily involved in aquifers depletion, some stressors affect groundwater condition (i.e., intense usage of pesticides and fertilizers to the land, waste from livestock and other
animals, landfills, mining operations) accidental releases. Some groundwater has high levels of naturally occurring dissolved solids or metals such as Arsenic found in natural rock formations.

These stressors can eventually affect the water quality available for drinking, irrigation, or other human needs and ecological systems. [1]

2. **Groundwater sustainability**
Groundwater sustainability is defined as the maintenance and protection of groundwater and related ecosystems to balance current and future environmental, economic, and human (social) requirements. [2]

According to USGS Circular 1186, groundwater sustainability is the development and use of groundwater resources to meet current and future beneficial uses without causing undesirable environmental or socio-economic consequences. [3]

Undesirable results specifically include reducing groundwater storage, lowering groundwater levels, seawater intrusion, degraded water quality, land subsidence, and depletion of interconnected surface water.

By protecting the groundwater supplies from depletion, monitoring the quantity is essential. By protecting the groundwater from contamination, monitoring its quality is crucial. Also, protecting the ecosystem viability, achieving economic and social well-being, and applying a good governance policy, can achieve groundwater sustainability. [4-8]

3. **Groundwater contamination risk assessment**
There are two main ways contamination reaches groundwater: point source pollution - when pollution comes mainly from spills, leaks, and discharges at a single point or over a small area and diffuse pollution – when pollution is often the result of cumulative impacts of small, undefined pollution.

Point source pollution is easy to identify because it results from mainly isolated events or activities with a clear link to groundwater pollution. In contrast, diffuse pollution is the most widespread cause of groundwater pollution.

Groundwater contamination risk assessment is an effective way to protect the safety of groundwater resource. To deal with the uncertainty in groundwater contamination risk assessment, we propose to use a detailed quantitative risk assessment DQRA. [9]

3.1. **Detailed Quantitative Risk Assessment – DQRA**
To protect groundwater from being contaminated, an assessment should be done to determine the level of risk posed by soil and groundwater contamination and establish if remediation is necessary to protect controlled waters from site derived contamination. Furthermore, should remediation be deemed necessary, site-specific remedial targets are to be derived.

A case study is presented below. A Conceptual Site Model was derived based on a "Source-Pathway-Receptor" exposure mechanism using historical information, a site walkover, and a geo-environmental site investigation. Soil contamination was identified at a former industrial site in Romania, and the primary sources of contamination are residual contamination within the soil and groundwater.

The following potential migration pathways have been identified: leaching from soil and migration of contaminated groundwater. The Environment Agency indicated that the site was located directly over an aquifer and within the Outer Source Protection Zone to potable groundwater abstraction.
Groundwater and soil samples were collected from the site and tested in the laboratory; the concentration of water samples and soil leachate test results were compared to Romanian Drinking Water Standards – table 1.

**Table 1.** Contaminant concentration levels.

| Determinant | Soil Concentration Leachate Test Results Average [μg /l] | Groundwater Concentration Average [μg /l] |
|-------------|--------------------------------------------------------|-----------------------------------------|
| Arsenic     | 85                                                     | 11.5                                    |

Based on the ground conditions and contaminants, a hydrogeologic risk assessment for land contamination has been carried out to predict the potential impacts of the identified contamination on the identified receptors. [10, 11]

Remedial target concentration is based on the maximum admissible Romanian drinking water concentration and is given in table 2. Site-specific partition coefficients were derived by laboratory testing.

**Table 2.** The remedial target value for contaminants of concern.

| Determinant | Target Concentration [μg /l] | Source                                      |
|-------------|------------------------------|---------------------------------------------|
| Arsenic     | 10                           | Romanian Drinking Water Standard            |

The Detailed Quantitative Risk Assessment (DQRA) has modelled contaminants' leaching from the site via infiltration and vertical migration to the groundwater and subsequent lateral groundwater migration, with dilution and attenuation process active, to the compliance point – as can be seen in figure 1.

**Figure 1.** Hydrogeological model: assessment levels and compliance points.
A Level 1 remedial target for soil was carried out – see below in figure 2.

The measured soil concentration for Arsenic (85 μg/l) exceeds the remedial target concentrations of 10 μg/l. Further actions are required. Therefore, there is a need to either upgrade the analysis level or implement remedial action. The estimated cost of remediation is significantly higher than the cost of further investigation, and a Level 2 assessment is undertaken: this includes the consideration of groundwater dilution (figure 1). For this analysis, the following groundwater parameters have been considered:

- L – length of site parallel to groundwater flow;
- i – hydraulic gradient;
- Mz – mixing zone thickness;
- da – aquifer thickness;
- Inf – infiltration;
- K – hydraulic conductivity;
- w – width of site.

And the following concentrations have the meaning as per below definitions:

- \( C_c \) – concentration of contaminant in contamination discharge;
- \( C_T \) – target concentration;
- \( C_U \) – background concentration of contaminant in groundwater.

A snapshot of Level 2 soil analysis is presented in figure 3.

The Dilution Factor calculated is \( DF = 7.97 \), giving a Level 2 remedial target of 79.7 μg/l. As the leaching tests results indicate, remedial action is required to protect the abstraction zone. However, further analysis could be carried out to consider attenuation of pollutants down hydraulic toward the compliance point.

In Figure 4, a snapshot of Level 3 soil calculation is presented.
The remedial target value of 91.5 μg/l (leachable Arsenic in soils) lies above the observed range of arsenic concentrations from leaching tests (average concentration of 85 μg/l). In this case, remedial action is no longer considered necessary. A groundwater monitoring scheme is recommended to be implemented.
to confirm that residual contamination in groundwater would not pose an unacceptable risk to the abstraction zone or controlled waters (river). The relative concentration, which is the ratio between arsenic concentration at a given point compared to source concentration, is presented in figure 5.

Figure 5. Relative concentration at compliance point for leachate

Figure 6. Level 3 groundwater risk assessment
Regarding groundwater risk assessment, at an instant evaluation (for Level 2 groundwater), the concentration of dissolved Arsenic in the boreholes (11.5 μg/ l) is higher than the target concentration of 10 μg/ l. Therefore, either a remedial action is required at this stage or further analyses to be carried out, taking into account the attenuation and dilution of the groundwater to the compliance point – Level 3 Groundwater. Using Ogata-Banks equation, the Remedial Target Concentration (RTC) for groundwater is determined using the same spreadsheet. A snapshot for Level 3 Groundwater is presented in figure 6.

Remedial Target Concentration at Level 3 groundwater risk assessment has a value of 11.6 μg/ l. This value is higher than groundwater concentration (11.5 μg/ l), and a "do nothing" outcome results from Level 3 risk assessment, which implies that dilution of contaminants (Arsenic in our case) in the environment is sufficient to mitigate adverse effects. The concentration of the contaminant of concern at the compliance point is 9.5 μg/ l, below the target concentration as per Romanian drinking water standard. Arsenic concentration variation within groundwater is shown in figure 7, starting at 11.5 μg/ l at source, reaching the compliance point within limits – below 10 μg/ l.

![Figure 7](image_url). The calculated concentration of As in groundwater towards compliance point.

### 3.2. Overview

When contamination of both soil and groundwater has been identified, the assessment should follow the Detailed Quantitative Risk Assessment (DQRA) approach. The objective should be to determine remedial targets for soil and groundwater and establish if remedial action is required for soil and/ or groundwater and should be given priority. The assessment should consider if remedial action is still required after the soil contamination has been removed and the link between the observed soil and groundwater contamination.

In this paper, both remedial target concentrations for soil and groundwater are below the existing concentrations. Therefore, no remedial measures are recommended as attenuation and dilution will "bring" the contaminant concentration at the compliance point below the target concentration of 10 μg/ l – as per Romanian drinking water standard.
4. Conclusions

It is essential to emphasize that water is a valuable resource, but it is a finite source and protecting the water means protecting all forms of the groundwater that can be found in aquifers. A detailed quantitative risk assessment of groundwater pollution has been performed to determine the level of risk posed by soil contamination (Arsenic) and establish if remediation strategies are required to protect the abstraction zone from site-derived contamination.

Assessment was carried out on three levels for soil (Level 1, 2 and 3) and two levels for groundwater (Level 2 and 3). Contaminant concentrations at the compliance point are lower than the target concentration derived from the Romanian water drinking standard for Arsenic. Furthermore, remediation is deemed NOT necessary. Therefore, site-specific remedial targets which were derived are higher than the current concentrations – either for groundwater or leachable Arsenic. Assessing groundwater contamination through a detailed quantitative risk assessment to build a sustainable future is a must for certain cases and should be accompanied by monitoring schemes – where required.

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