Soil Remediation Strategies based on Risk Assessment Approach

Camelia Madear¹, Emilia-Cornelia Dunca², Gelu Madear¹

¹ECO-ROCCA Engineering, 3, Mihai Viteazu Street, Petrosani, Hunedoara, Romania
²University of Petrosani, 20, Universitatii Street, Petrosani, Hunedoara, Romania

camelia.madear@eco-rocca.ro

Abstract. Anthropic activities are characterised by benefits and drawbacks for the human being and the environment. In the last few centuries of the humankind, the industrial activity has increased exponentially due to massive industrialisation process. This evolution has augmented the use of land for industrial purposes, which in turn affected the quality of soil by polluting it with high levels of chemical contaminants. On the other hand, intensive agricultural activities involve the use of pesticides and fertilisers, which at the end of the day, also contribute to the contamination of the agricultural land. Soil may be contaminated as well by accidents which occur due to human activity. The land quality is essential to preserve the environment, and it is required to maintain the level of pollution within legal limits. If contaminant levels are above the legal limits, then a soil remediation action plan should take place. Very high costs are usually associated with soil remediation, and the best strategies should be adopted to optimise resources and costs. A methodology to derive remedial targets has been successfully used in the USA and adopted and adapted in various countries inclusive in the EU. Currently, Romania has started to follow specific steps to align with international practices regarding the management of contaminated land. Although this methodology is extensively used in western countries, its application in Romania is in its inception phase. Therefore, this paper intends to present the current situation in Romania regarding the contaminated sites and potentially contaminated sites, the risk assessment approach that should be followed and the related soil remediation strategies that could be implemented.

1. Introduction
Like most industrial societies around the world, Europe has thousands of contaminated sites which are mainly the result of earlier industrialisation and inadequate environmental management practices. Where these sites have been affected by contamination, it may present a risk to a range of receptors, including humans, ecosystems, water quality, and property, including crops and animals.

Following its industrial activities, Romania also has a legacy of 1393 contaminated or potentially contaminated sites. This large number of sites might be due to a lack of Romanian legislation of a legal framework for the pollution prevention and control of the land (surface soils and sub-soils). The Romanian legal framework for contaminated and potentially contaminated sites impose specific regulations and methodologies to screen, investigate and finally remediate those sites which might pose unacceptable risks to the land use for the human health and environment.
Contaminated land/ soil remediation is one of the main components of the sustainable development process for each community at various administrative levels. Land remediation is an essential process in the improvement of the quality of life, environmental conditions, and economic development.

There are a few industries in Romania which have primarily contributed to the land contamination as follows:

- **Mining & Metallurgy** – these are activities as old as we can identify the existence of Romanians 2000 years ago before being conquered by the Roman Empire, and mainly mining for gold, silver and salt. After that, mining has developed for other minerals such as coal, uranium, copper or iron, to mention a few from more than 60 minerals mined to date. Associated with mining were the mineral processing and metallurgy. All these activities are now mostly closed down. However, they left behind many contaminated sites (chemically and physically degraded), inclusive of waste dumps and tailings ponds, which are now a legacy for the Romanian society and next generations, having a significant impact to human health and environment. Soil and groundwater contamination took place in time and contain heavy metals, cyanides, hydrocarbons, acid waters, saline waters;

- **Chemistry** - Romania had several chemical, petrochemical, and pharmaceutical facilities. Some of them are still in use whereas most of them are now abandoned, and the sites are in a dire need of rehabilitation. There are many chemicals still present on these sites and are potential sources for contamination posing also high risks for human health and the environment. The pollution at these sites is very complex and diverse and requires a thorough investigation;

- **Oil industry** - has more than 150 years of history in Romania and is characterised by the existence of multiple sites from extraction wells to oil deposits, refineries, pipelines, and ponds. Both soil and groundwater are contaminated with light/ heavy hydrocarbons and heavy metals (lead, zinc, copper, nickel);

- **Old pesticides deposits** - although placed on small surfaces, they are heavily contaminated and present a very high risk for human health and environment;

- **Other industrial activities** – such as non-compliant municipal waste landfills, military sites, steel plants, wood yards or coal power plants.[1, 2]

Although there are some general remediation techniques for all the contaminants/ pollutants mentioned above, the specific remediation option for a particular site would depend on some factors:

- Type of pollutant(s);
- Source-Pathway-Receptor linkages;
- Geological ground conditions;
- Receptors identified on-site.

Therefore, the proposed soil remediation strategy, following Romanian legislation, is based on a risk assessment approach of the contaminated site on human health and environment and options appraisal.

There is a massive task for the Romanian society to rehabilitate all potentially contaminated or contaminated sites and requires not only financial resources but specialists/ consultants able to investigate, assess and propose remediation options for each site, not to mention specialised contractors in various remediation techniques. Romanian Environmental Agency carried out a preliminary inventory process to identify potentially contaminated or contaminated sites, based on a set of screening criteria for each type of sites. To understand the size and volume of the problem, figure 1 shows the regional distribution of the potentially contaminated sites in Romania (with a total of 1183) and figure 2 shows the distribution of the contaminated sites (confirmed) for each county to a total of 210 sites.
1.1. Potentially Contaminated Sites
These are sites with a recorded history regarding the land use but without having done any site investigations and generic or detailed risk assessment. They were included within this category based on their historical activities, and their final characterisation as contaminated (or not) is subjected to further investigation.

![Romanian Distribution of Potentially Contaminated Sites per Counties](image1)

**Figure 1.** Romanian distribution of potentially contaminated sites per counties

1.2. Contaminated Sites
These are sites with a recorded history in land use and have done some site investigations and a form of risk assessment (Generic or Detailed Quantitative Risk Assessment). They were included within this category based on their historical activities, and their owners are responsible for the remediation.

![Romanian Distribution of Contaminated Sites per Counties](image2)

**Figure 2.** Romanian distribution of contaminated sites per counties

2. Contaminated Land/ Site Risk Assessment
Contaminated land risk assessment is the process which spans over several certain activities, used to certify that a site will not present unacceptable risks to those occupying or using it. The level of risk is closely related to the proposed use, and it is not associated with absolute values of contamination alone. This process is known as “the suitable for use approach”.[3]
It is crucial to understand from the very beginning that doing a risk assessment is an important task because it underpins the risk-based management of soil and groundwater contamination. Risk-based management is assessing the risk and taking actions where those risks are considered to be unacceptable. Also, by doing a risk assessment, it informs sustainable management of soil and groundwater contamination, identifies those sites where there is no unacceptable risk, and further work is not necessary. More than that, doing a risk assessment provides an objective method for identifying the need for remediation/risk mitigation, and it helps to prioritise and focus resources on sites where risks are high. [4]

The risks of the 210 contaminated sites identified so far in Romania can be associated with soil and groundwater contamination and pose various risks to: Human health from exposure to hazardous substances; Water resources; Ecology and safety; Property in the form of building foundations and crops; Archaeological resources and ancient monuments.

Carrying out a risk assessment can be a highly detailed process mainly where risks are involved. Assessing risks also means to estimate what might happen and how bad it would be and use this knowledge to help make decisions. Uncertainties must be reduced where it is possible and clearly explain the ones that remain. According to the UK Model Procedures for the Management of Land Contamination (CLR11) document, a tiered approach is recommended to do a risk assessment, and this is presented in table 1. A similar procedure has been proposed recently to be used in Romania.

Table 1. The tiered approach

| Risk-based corrective action | UK Terminology | Components |
|-----------------------------|----------------|------------|
| RBCA (USA)                  | Preliminary Risk Assessment (PRA) | Problem Formulation: Defining objectives, Describing context, Developing a Conceptual Site Model (CSM) |
|                             | Generic Quantitative Risk Assessment (GQRA) | Revised CSM, Comparison of measured site concentration with generic screening levels |
| Tier 1                      | Detailed Quantitative Risk Assessment (DQRA) | Revised CSM, Risk modelling using site-specific data |
| Tier 2                      | Revised CSM, More complex risk modelling having collected data |

Once the need for risk assessment has been identified, it will always be necessary to carry out a Preliminary Risk Assessment and deal with problem formulation, which is a planning phase of the risk assessment. This stage involves the followings: description of the context and emphasising why assessing the risks is so essential; state the objectives and scope of the risk assessment understanding what risks need to be assessed and how they will be assessed; develop the conceptual site model (CSM); conduct a qualitative assessment of which Source-Pathway-Receptor pollutant linkages could plausibly lead to unacceptable risk; plan how to address, assess or manage these linkages.

Tier 1 screening or Generic Quantitative Risk Assessment is the next step after doing the problem formulation, developing the Conceptual Site Model (CSM) and identifying the plausible pollutant linkages. Assessing even further means comparing measured site concentrations with generic screening values to assess risk properly. The importance of doing Tier 1 screening is because where the CSM has identified some plausible pollutant linkages, there is a potential risk and needs to decide if risks are significant or of concern. Tier 1 screening can provide a quick method for assessing the significance of
risks from one or more pollutant linkages. Also, it can help us to eliminate pollutant linkages from further assessment or to identify Constituents of Potential Concern (COPC) for Tier 2 Risk Assessment.

Tier 2 screening or Detailed Quantitative Risk Assessment is composed of two parts. First part is the revision of the Conceptual Site Model in conjunction with the new data. The second part involves the use of Risk Assessment models with more representative site-specific data to assess risk, rather than to use the generic screening values used in Tier 1.

Tier 3 analysis may include a proposal for additional site assessment, the use of probabilistic evaluations, or more sophisticated chemical fate and transport models.

3. Soil Remediation Strategies

Ground remediation strategy is the second stage of the overall process of contaminated land risk management. If the risk assessment process shows that unacceptable risks are associated with a contaminated site, then remediation strategies must be considered. As remediation strategies proceed, it focuses mainly on those pollutant linkages - relevant pollutant linkages, that have been derived through risk assessment to represent unacceptable risks. Usually, there are three stages in developing a soil remediation strategy: To identify for each relevant pollutant linkage the most feasible remediation options; To identify the most appropriate option for any particular linkage; this can be done through a detailed evaluation of feasible remediation options; To derive a soil remediation strategy that addresses all relevant pollutant linkages.

During the process of deriving a soil remediation strategy, firstly each relevant pollutant linkage is considered on an individual basis, by using a set of formal evaluation criteria, the most appropriate remediation option is identified. Soil remediation goals relate directly to the need to address pollutant linkages by decreasing contaminant mass, concentration, mobility, toxicity. Another way to reduce or control unacceptable risks would be by total isolation of the contaminant (remove or treat the source of pollutant) or through the management of the receptor (remove or modify the behaviour of receptor) or pathway (remove or modify the pathway). Within each of these categories, there may be different technical options. For example, it is possible to remove or treat pollutants using a variety of physical, chemical, or biological means. Remediation techniques may also be applied on an ex-situ or in-situ basis.

Once remediation objectives have been determined, site-specific remediation criteria need to be developed. Remediation criteria provide a measure against which compliance with remediation objectives can be measured. Examples of quantitative measures include: Guideline values: soil guideline values, drinking water standards; Site-specific assessment criteria developed from detailed quantitative risk assessment; Engineering-based criteria: the thickness and permeability of a cover system.[5]

At the end of the process, a report that summarises the chosen solutions and rationale behind it would constitute the ‘soil remediation strategy’. For a sustainable remediation process, the following technologies presented in figure 3 might be suitable within Romanian context for the treatment of Source, Pathway and Receptor:
4. Conclusions

Contaminated land/soil remediation was designed to remedy contamination and reduce risks to human health and/or the environment. However, if it is poorly selected, designed and implemented, remediation activities have the potential to cause more significant environmental, economic and social impacts than the contamination that they seek to address. Romania, being in the early stages of addressing the remediation strategies and technologies, should focus on embarking into a sustainable remediation process. The best approach in this direction and the most appropriate solution is the remediation that eliminates and/or controls unacceptable risks in a safe and timely manner, and which maximises the overall environmental, social and economic benefits of the remediation work. [6]

References
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