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# Green and sustainable site remediation: Incorporating broader economic impacts

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ABSTRACT: In the face of global climate change, ever-growing population, and rapid urbanisation, the idea of sustainability and sustainable development has gained significant attention as a greater solution to these problems. Environmental remediation of historic and newly identified contaminated sites involve the use of energy and resource intensive activities which have major broader environmental impacts that can substantially contribute to the aforementioned global problems, thus leaving the net environmental benefit from the remediation of contaminated site, questionable. Realizing this, the interest in the use of sustainable practices in environmental remediation has been increasing in recent years. Over the years, several qualitative and quantitative tools/frameworks have been developed to assess the environmental impacts and identify the most environmentally sustainable remedial strategy/technology from a range of potential remedial alternatives. However, the economic and social impacts which form the major components of sustainable development have not been addressed adequately in the published tools/frameworks. In this study, an overview of the concept of green and sustainable remediation is presented. A detailed discussion specifically on the broader economic impacts of site remediation and their inclusion in the triple bottom line sustainability assessment is provided with an example case study.

## 1 INTRODUCTION

Despite having strict environmental laws and regulations, the number of historic and newly identified contaminated sites posing significant human health and environmental risk have been increasing. Over the years several remediation technologies ranging from ex-situ to in-situ remediation methods have been developed based on their suitability to different site characteristics including contaminated media (e.g. soil, groundwater, sediments), type of contaminants (e.g. heavy metals, organic compounds), extent of contamination (e.g. surficial, sub surficial, deep) and other site characteristics (Reddy & Adams 2015). In the current practice for environmental remediation, remedial strategies or technologies are chosen based on their ability to reduce the concentrations of the contaminants of concern to risk-based levels, the cost of implementation, and remediation timeframe. The secondary environmental impacts from the energy and resource intensive remedial activities involved in a remediation project are often unaccounted for in the decision for remedial actions. It is therefore not realized that remediation activities may cause more environmental damage indirectly at a global level than the environmental damage that could possibly be incurred due to the contamination at the site.

Realizing this issue, in recent years, there have been significant efforts to quantify the environmental sustainability of the potential remedial options/strategies that suit the site-specific characteristics, identification and subsequently implement the most sustainable remedial option at the site. Several tools and frameworks have been developed by federal agencies, international organizations, private companies and academic researchers to aid in assessing and quantifying the environmental impacts of the remedial options. However, these tools did not address the broader economic impacts that are incurred during the entire life cycle of the remediation project, adequately. In general, the economic sustainability of the remedial options is considered based on the direct costs (e.g. cost of materials, equipment, labour, transportation, disposal, permit, etc.) incurred in the entire life cycle project. The indirect costs that may result from the environmental and social impacts during the life cycle of a remediation project are usually not accounted. It is imperative to ensure that the remedial option/strategy chosen for implementation at the site is environmentally, economically and socially sustainable in order for it to be regarded as a green and sustainable remediation.

This study is focused on assessment and quantification of the broader economic impacts as a result of environmental impacts from the remedial strategy/technology implementation at a site. A case study involving the remediation of contaminated sediments is used to demonstrate the importance of including the secondary economic impacts on sustainability of the remedial strategy. A life cycle assessment (LCA) of the potential remedial options for the remediation of contaminated sediments and other site characteristics is performed and its results are monetized using a monetization technique embedded into an LCA software (SimaPro v8.5). The influence of the monetised costs of environmental impacts on the decision of the most sustainable remedial option is discussed. Further, the opportunities in improvising these methods are highlighted.

## 2 GREEN AND SUSTAINABLE REMEDIATION

The concept of green and sustainable remediation (GSR) has emerged with a need to minimize the secondary environmental, economic and social impacts while still meeting the site-specific remedial goals and regulatory objectives. According to the Interstate Technology & Regulatory Council (ITRC), GSR is defined as "the site-specific employment of products, processes, technologies, and procedures that mitigate contaminant risk to receptors while making decisions that are cognizant of balancing community goals, economic impacts, and environmental effects". The reduction of environmental impacts may involve minimizing the energy and resource use and their associated emissions (environmental footprint), minimizing the waste generation, and recycling or use of waste materials, as applicable. In addition, the reduction in economic and social impacts include minimizing the project costs incurred from various activities involved in the remediation project and minimizing the direct and indirect impacts on the residents and community (society) around the contaminated site where the remedy is implemented. Thus, GSR promotes consideration of holistic impacts of remediation to manage the remedial activities wisely and subsequently aid in a sound decision and contribution to global sustainable development. The ITRC while incorporating the idea of green remediation from the USEPA's core elements for greener cleanup also recognizes that there is great potential for growth of the consideration to economic and social aspects of sustainability in remedial decision making. A detailed discussion on the evolution of the concept of GSR is presented in (ITRC 2011, Reddy et al. 2018a, b).

## 3 BROADER ECONOMIC IMPACTS

The economic impacts of remediation projects are usually assessed as a part of the sustainability assessment of potential remedial alternatives and they generally have been limited to direct costs associated with the remedial alternative. However, this leads to an incomplete and inaccurate assessment of sustainability of the remedial design alternative. It is essential to include the indirect costs as well as the benefits associated with implementation of each of the remedial design alternative for a holistic consideration of the economic impacts of the remediation project. The following section discusses the three most common methods used for economic impact assessment of remedial alternatives for sustainable remediation.

### 3.1 *Life cycle cost assessment (LCCA)*

LCCA is a more realistic method of comparing the total direct costs of the remedial alternatives than simply comparing the initial implementation costs. The life-cycle cost refers to all the potential costs incurred during the entire life cycle of the remediation project. This includes the cost of planning and design, initial capital and administrative costs, cost of operation including the cost of labor, materials, utilities, fuel, and maintenance including sampling and analysis, equipment lease/rental, off-site disposal fees, administrative costs (e.g., permitting fees, reporting, fines for violations), and cost of disposal of generated wastes. In a formal sense, the LCCA evaluates the total cost of ownership over the life span of the project and compares the present worth of the total annual costs of ownership for different remedial alternatives (ITRC 2006).

According to the ITRC guide for LCCA for remediation process optimization, the life cycle cost estimation should address the key cost components of the remedial actions, operations and maintenance activities (direct costs); uncertainty in the costs; discount rates for present value or scale-up factors for future inflation; time expected to achieve remedial goals and objectives, periodic capital, and operation and maintenance anticipated in future years of the remediation project; decommissioning costs after project closure; resources used for preparing the cost estimates; and treatability studies costs, if applicable.

The present worth of the life-cycle cost is often based on a single cost number referred to as the net present value (NPV). The NPV is indicative of the forecasted funds that must be available to ensure that the remedial design could be successfully implemented as planned and designed. The calculation of the NPV should also account for the discount value for realistic comparison for the remedial alternatives. The NPV can be calculated using Equation 1 given below.

$$NPV = \sum_{1}^{n} \frac{Annual\ cost\ in\ year\ t\ with\ inflation}{(1+r)^{t-1}} \quad (1)$$

where, r is the annual discount rate; n is the total number of years of remediation.

### 3.2 *Cost-benefit analysis (CBA)*

CBA is another most commonly used analysis method for quantification of the economic impacts of remediation. CBA is different in that, it considers the indirect costs (e.g. the cost of $CO_2$ emissions from remediation activities based on its environmental impact) as well as benefits (e.g. reduced health risk from remediation, enhanced protectiveness of workers and residents, ecosystem improvements, reduced time to achieve remedial goals, and future use of site). In an ideal CBA all the impacts to society are included, and the net present value (NPV) is calculated for a remedial alternative by accounting for the direct and indirect costs and benefits as well as the health and environmental benefits and other relevant impacts. It is important to conduct the CBA keeping in view all the stakeholders that may be affected from the remedial action.

The NPV (see equation 2) obtained for the CBA method comprises of all costs ($C_t$) and benefits ($B_t$) that are aggregated and weighed over an anticipated remediation time period (t). A discount rate (r) that accounts for the depreciation of the value of money over time is used. The remedial strategy is deemed to be economically beneficial/profitable if the NPV of that alternative is determined to be positive.

$$NPV = \sum_{t=0}^{T} \frac{1}{(1+r)^t} (B_t - C_t) \qquad (2)$$

where, T is the time horizon associated with the benefits and costs. It should be noted that neither the NPV from the LCCA nor the NPV of the CBA is enough to decide if the remedial design is sustainable.

### 3.3 *Monetized LCA (MLCA)*

LCA is a well-known standardized method of quantifying the environmental impacts and thereby the environmental sustainability of remedial alternatives. Likewise, MLCA is a decision tool used to assess and quantify the indirect costs of the environmental impacts from remediation activities involved during the entire life cycle of a remediation project. MLCA is particularly important in the context of environmental remediation due to the environmental emissions and impacts from large amounts of resources, energy and fuel used in remediation activities. MLCA essentially is an approach that expresses the environmental impacts in terms of a monetary value. The application of MLCA method was earlier limited to consumer products, food industry and construction works, and waste management works until recently where it has slowly gained prominence in site remediation as well (Huysegoms et al. 2018). Some of the tools available for MLCA are Stepwise 2006 (Pizzol et al. 2015, Weidema 2009), Ecovalue 2008 (Ahlroth & Finnveden 2011), Ecotax 2002 (Eldh & Johansson 2006) and LIME (Itsubo et al. 2012, 2004). A brief summary of the methodology used in monetization of the environmental impacts in each of these techniques is presented in Huysegoms et al. (2018). MLCA in addition to the LCCA and CBA can provide a comprehensive analysis of the economic impacts of the remedial alternatives and thus aid in true green and sustainable remediation.

## 4 CASE STUDY

### 4.1 *Background*

The site in this case study dealt with the remediation of sediments at Cedar Lake in Iowa, USA. Cedar Lake is currently fed from three sources: a small creek called McLoud Run, treated cooling water from Cargill Incorporated, and the Kenwood Ditch Outfall. The Kenwood Ditch Outfall is a 5.8 m by 3 m box culvert that discharges into South Lake during storm events. This sewer serves as a drainage basin comprising approximately 15.54 $km^2$ of Cedar Rapids, including residential and commercial areas. The geology of the site consists primarily of quiet-water sediments within North Lake. South Lake is dominated by the delta deposit near the Kenwood Ditch Outfall, which consists of coarser-grained sand and gravel deposits near the outfall which grade finer with distance.

A preliminary site investigation found elevated concentrations of both PCBs (polychlorinated biphenyls) and pesticides throughout the North Lake and South Lake with concentrations up to 1 part per million (ppm). In the Phase II site assessment, samples were collected using a hand auger from the top 0.61 m of sediment at sample points located along a grid system across the Lake. Multiple samples located within the South Lake by the Kenwood Ditch Outfall, exceeded the Probable Effects Concentration (PEC) for either pesticides or Polychlorinated biphenyls (PCBs). The final area was determined by using the halfway rule. Half the distance between a sample exceeding the PEC and a sample below the PEC was determined to be the edge of remediation. A total of 776.79 $m^2$ of sediment exceed the PEC for at least one contaminant of concern and will require further remediation.

The studies from 1994 and 2017 showed a decrease in concentrations of contaminants as high as one order of magnitude. Based on this observation, MNA with a monitoring program for at least 20 years (based on the sediment deposition rate and contaminant concentrations) was considered as one of the remedial measures for the passive remediation of site. Further, based on the site characteristics and feasibility evaluation of different relevant remedial technologies, dredging of contaminated sediment, conventional capping of the sediment, and modified capping with reactive core mat were identified as potential remedial alternatives for the remediation of site. A detailed explanation on the preliminary design of all the four remedial alternatives are presented in Reddy et al. (2018c).

### 4.2 *Methodology*

In this paper, a monetized LCA was performed for the remedial options for this site with contaminated sediments and a comparison was made with the direct costs and indirect costs associated with each of the remedial option. The Stepwise 2006 V1.05 / Europe95 impact assessment method implemented in the LCA software SimaPro 8.5 was used to perform the monetized LCA. The inputs for the LCA and the environmental impacts as reported in Reddy et al. (2018c) were used. The results from monetized LCA were obtained in terms of Euros (of the year 2003) which were converted to US dollar (USD) of the respective year. For the comparison of the monetized LCA results with the direct costs which were expressed in USD 2017, monetized LCA costs were recalculated incorporating the inflation rates.

### 4.3 *Results*

Table 1 shows the monetized values of each environmental impact category in terms of value of US Dollars for the year 2003. The positive values imply the cost of environmental impact and adds to the total cost of the project while negative value implies benefits. Each remedial option shows positive value for each impact category meaning the cost of environmental impacts are additive to the total cost of the project. Table 2 shows the comparison of the direct costs and the environmental impacts costs in terms of USD of the year 2017 for each remedial option. Comparing direct costs associated with the life cycle stages of the activity or project is a common practice while assessing the economic sustainability. In this case study, the assessment of the direct costs alone shows that dredging and disposal as the most unsustainable option economically. However, the cost associated with the environmental impacts of the remedial option is highest for the conventional capping option as shown in Table 2. In addition, the conventional capping has the highest total cost. It can be inferred that the costs associated with the environmental impacts of the remedial options can alter the decisions that are solely based on economic sustainability assessment involving only the direct costs. Ignoring environmental impact costs can not only result in underestimation of the overall economic impacts of a remedial option but also undermine the unanticipated benefits which are not apparent unless a thorough and rigorous analysis as such is conducted. It can ultimately affect the decision-making process.

Table 3 shows the comparison of the direct costs, social costs based on 3% discounted rate (USEPA, 2017), and $CO_2$ emission costs as obtained from the monetized LCA for the life cycle stages of conventional capping option. The results show that the $CO_2$ emissions are more from transportation than the excavation and dredging operations. The costs associated with the emissions is more than the direct cost of the activities. It also shows difference in the social cost of $CO_2$ obtained from USEPA (2017) and the monetized LCA which can be attributed to the monetary conversion units built into the Stepwise 2006 method. However, the social cost from both the methods (USEPA and Stepwise 2006) follow the same trend for different remedial options as shown in Table 3.

Table 1. Monetized LCA results per impact categories for each remedial alternative (in USD)

| Impact category | Impact unit | MNA | Dredging & Disposal | Conventional Capping | Modified Capping |
|---|---|---|---|---|---|
| Human toxicity, carcinogen | kg $C_2H_3Cl$-eq | 76 | 586 | 5,315 | 2,983 |
| Human toxicity, non-carcinogen | kg $C_2H_3Cl$-eq | 48 | 2,155 | 4,906 | 2,996 |
| Respiratory inorganics | kg $PM_{2.5}$-eq | 1 | 319 | 617 | 402 |
| Ionizing radiation | Bq $C^{14}$-eq | 6,818 | 2,101,346 | 4,636,539 | 3,230,415 |
| Ozone layer depletion | kg CFC-11-eq | 0 | 0 | 0 | 0 |
| Ecotoxicity, aquatic | kg TEG-eq w | 109,031 | 4,714,142 | 9,523,042 | 6,240,578 |
| Ecotoxicity, terrestrial | kg TEG-eq s | 6,050 | 3,366,435 | 4,156,642 | 2,606,085 |
| Nature occupation | $m^2$-years agr | 16 | 7,001 | 15,661 | 9,688 |
| Global warming, non-fossil | kg $CO_2$-eq | -1 | 3 | 616 | -49 |
| Global warming, fossil | kg $CO_2$-eq | 1,382 | 197,762 | 395,000 | 300,174 |
| Acidification | $m^2$ UES | 67 | 12,675 | 35,057 | 24,471 |
| Eutrophication, aquatic | kg $NO_3$-eq | 0 | 163 | 242 | 499 |
| Eutrophication, terrestrial | $m^2$ UES | 140 | 62,397 | 98,394 | 64,348 |
| Respiratory organics | Pers-ppm-h | 1 | 325 | 537 | 358 |
| Photochemical ozone, vegetation | $m^2$-ppm-hours | 12,695 | 3,969,179 | 6,395,665 | 4,241,879 |
| Non-renewable energy | MJ primary | 15,422 | 2,865,795 | 4,873948 | 5,260,804 |
| Mineral extraction | MJ extra | 76 | 3,488 | 17,826 | 10,150 |

Table 2. Comparison of direct cost and the monetized cost of the environmental impacts

| Cost Type | MNA | Dredging & Disposal | Conventional Capping | Modified Capping |
|---|---|---|---|---|
| Direct Cost (USD) | 545,100 | 1,447,101 | 806,404 | 751,731 |
| Monetized LCA cost (USD) | 201,924 | 23,014,015 | 40,112,810 | 29,254,390 |
| Total (USD) | 747,024 | 24,461,116 | 40,919,214 | 30,006,121 |

Table 3. Comparison of direct cost and $CO_2$ emission cost of each activity involved in conventional capping

| Life Cycle stages | Direct Cost (USD) | [a]Social Cost of $CO_2$ (USD) | [b]$CO_2$ Emission Cost (USD) |
|---|---|---|---|
| Excavation of sediments/Dredging | 173,398 | 133 | 5,128 |
| Transportation of dredged material | 14,046 | 2,848 | 109,142 |
| Transportation of gravel (1”-1.25”) | 11,120 | 3,505 | 130,892 |
| Transportation of gravel (3”-4”) | 6,356 | 2,003 | 74,789 |
| Transportation of sand | 23,835 | 5,292 | 200,271 |

[a] = Social cost of $CO_2$ based on 3% discounted rate (USEPA, 2017)
[b] = Cost of $CO_2$ based on the monetized LCA

## 5 CONCLUSIONS

Green and sustainable remediation has been an important and a relevant shift in the way environmental remediation has been done since many years. This has a great potential for significant contribution towards sustainable development and consequently playing its part in addressing the grand challenges of the 21st century. In order to realize that, the remedial decision has to be based on a sound and quantitative assessment of the environmental, economic and social impacts to the least to aid in selecting the most suitable and sustainable remedial design for implementation at the site. The existing tools are heavily inclined towards environmental impacts/concerns of remediation with no regard to the broader economic and social impacts. This study addresses the economic aspects of site remediation by invoking the need to include the indirect costs and benefits of remedial design alternatives in addition to their direct costs while assessing their economic sustainability.

The case study discussed in this paper revealed that a remedial option which may seem beneficial in terms of direct costs may result in higher indirect costs from the environmental impacts. Thus, techniques such as monetized LCA in conjunction to the cost benefit analysis with a life cycle approach is an appropriate and more reliable way for quantifying the sustainability of the remedial options.

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