Assessment of Spatial Analysis and Decision Assistance (SADA) Potential for Clean Up

Sambanis A.[1*] and Cailas M.[1]

[1] University of Illinois at Chicago School of Public Health Department of Environmental and Occupational Health Science Emergency Management and Continuity Planning Graduate Certificate Program

*corresponding author:

e-mail: asamba2@uic.edu

Abstract United States (U.S.) federal and state regulations related to brownfields promote applicable practices that contain inherent problems. The primary issue with federal and state regulations governing brownfields is that risk assessment measures and spatial distribution of contaminants are not prominently factored in brownfield redevelopment. These boundaries of the contaminants are critical for establishing proper protection of the potential exposed population such as clean-up workers. Public domain software developments such as the Spatial Analysis and Decision Assistance (SADA) software can provide a reliable and cost effective tool for developing a comprehensive approach to brownfield redevelopment which will account for the spatial distribution of the contaminants and provide a rational solution to critical operational issues such as hotspots, restrictive zones for the protection of workers, and prioritization of clean-up operations. Actual data from a brownfield site in Cook County, Illinois, was used in this study to evaluate SADA applicability to brownfield redevelopment. Soil data from historical investigations were captured within SADA to identify hotspots of contaminants of concern and to create worker restrictive zones based on future redevelopment. The results for the brownfield site classified statically significant to actual results observed, and it appears that SADA is an appropriate tool for brownfield redevelopment.

Keywords: Risk Visualization, Modelling, Spatial Distribution

1. Introduction

The Small Business Liability Relief and Brownfields Revitalization Act, passed in 2001 (Public Law 107-118, H.R. 2869), defines brownfields as "real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant." The extent of contamination encountered at brownfield sites may range from surface debris to soil and groundwater contamination that can be hazardous to human and ecological health (Knowlton and Minier, 2001). The United States Environmental Protection Agency (USEPA) estimated that there are more than 450,000 brownfields in the U.S., and approximately one-half are thought to be contaminated by leaking underground storage tanks (USEPA, 2011). Brownfield properties historically were not revitalized, due in part to distress of environmental contamination which is typically associated with high cleanup costs, extensive cleanup processes, liability risks, and lack of government participation (Schenck, 2004). Brownfield sites have the potential to impair human health and the environment, diminish employment opportunities and tax revenue, deter economic growth and attract illegal activity, thus lowering surrounding property values and contributing to the overall decline of the quality of life in the neighborhood (Simon, 2001). Communities across the U.S. have begun to appreciate that brownfield redevelopment can alter a brownfield into productive uses that can subsequently bring improved public health and environment, economic growth and increases in employment openings (Ruiz-Esquide, 2004).

Current federal and state regulations related to brownfields promote applicable practices that contain inherent problems. The primary issue with federal and state regulations governing brownfields is that risk assessment measures are not prominently factored in brownfield redevelopment. A case in point is the lack of a comprehensive approach to brownfield redevelopment that will account for the spatial distribution of the contaminants. The boundaries of these contaminants are critical for establishing proper protection of the potential exposed population such as clean-up workers. Recent public domain software developments such as the Spatial Analysis and Decision Assistance (SADA) software can provide a reliable and cost effective tool for developing a comprehensive approach to brownfield redevelopment that will account for the spatial distribution of the contaminants and provide a rational solution to critical operational issues such as hotspots, restrictive zones for the protection of workers, and prioritization of clean-up operations. The spatial defined information would allow site investigators to visualize the extent of the contamination, therefore minimizing the uncertainty while providing accurate results to reduce expenditures during data collection and remediation.

The spatial database used in this study (SADA) was developed by the University of Tennessee in Knoxville and the USEPA; according to SADA documentation the original "…purpose of the effort was to develop tools that would integrate human health and ecological risk assessment with geospatial processes in a manner that could directly impact environmental restoration decisions." (SADA, 2008). The overall objective of this study was to assess the applicability of SADA as an analysis, interpretation, and design tool for brownfield redevelopment. The specific objectives of this study are:

- To assess the applicability of SADA for the identification of potential high risk areas in a brownfield site with the objective to protect construction workers and trespassing recreational persons; and

- To use SADA to prioritize clean-up operations and creation of restrictive zones.

To these aims, actual data from a real-world brownfield site in Cook County, Illinois, was used in this study. This is the first time the applicability of this health risk spatial database has been investigated for such a scope. The results from this study could be used as a demonstration project to promote the use of risk assessment and spatial visualization techniques as a useful tool for brownfield redevelopment.

2. Regulatory Framework

2.1. U.S. Federal laws governing brownfields

The two most significant federal laws that regulate brownfields are the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA) (CERCLA, 1980 and Powell, 1998). CERCLA and RCRA determine parties who are potentially liable for cleanup costs at contaminated sites: owners and operators of the property, generators of the hazardous substances, and transporters of the hazardous substances (Murphy, 1986). Under CERCLA, anyone could be held accountable for all the costs of cleanup, even if they only contributed a small proportion of the waste at the site (USEPA, 1989). A recent purchaser of a property could be held accountable for all the expenses of cleanup at a site without the proper due diligence (USEPA, 1989). The government soon recognized that CERLCA was deterring brownfield redevelopment.

a. Illinois laws governing brownfields

The Illinois law that is most applicable to contaminated sites is the Illinois Environmental Protection Act (Layman and Northrup, 1998). As stated in the Memorandum of Understanding between the Illinois Environmental Protection Agency (IEPA) and USEPA on the Illinois Site Remediation Program (SRP), Illinois Tiered Approach to Corrective Action Objectives (TACO), and the Environmental Remediation Programs administered by the Region 5 Waste, Pesticides, and Toxic Division under RCRA and TSCA dated June 1997, IEPA and Region V began developing strategies to promote the remediation and redevelopment of brownfield sites (IEPA, 1997). TACO is the IEPA's process for developing remediation objectives for contaminated soil and groundwater (IEPA, 1997). The IEPA has operated SRP, which provides management, aid, and oversight to owners and operators of sites in Illinois who implement site assessment and remediation. TACO allows site owners and developers to remediate the site to the proper tier based on risk (IEPA, 1997). The IEPA established remediation objectives were used in this study.

3. History of the Property

An actual brownfield site, from here on termed the Property, was used for this demonstration project. The Property is an approximately 3.68-acre parcel of land that currently contains one single-story industrial building (Figure 1). The Property was used for metal stamping and die drawing for approximately 58 years. The surrounding properties are primarily industrial and mixed commercial use. Previous site investigations conducted at the Property identified that unknown fill materials were present within the location of a former clay pit; and that an abandoned heating oil underground storage tank (UST) was present on the north part of the Property. This Property fits the criteria of a brownfield due to the potential presence of contamination.

The current study used actual soil data from this brownfield site to assess the objectives stated earlier. Multiple sites were being investigated within Cook County, Illinois, but the Property was ideal for this investigation for the following reasons: The site fulfills the criteria of a brownfield; had historical investigation data that could be used as a base to determine the contaminants of concern; and was suspected to contain contamination. The extent of contamination that might be encountered at the site was unclear.

Based on the data from the historical site investigations, the following contaminants were identified:

- Soil contaminated with cis-1,2-dichloroethene trans-1,2-dichloroethene, and trichloroethylene (TCE) was observed at concentrations exceeding the IEPA TACO Tier 1 Soil Remediation Objectives (SROs) within soil samples collected from the northwestern of the building on the Property.

- Concentrations of benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, dibenz(a,h)anthracene, indeno(1,2,3-cd)pyrene, naphthalene and mercury in three soil samples on the northern portion of the Property exceed their IEPA TACO Tier 1 SROs.

- Lead contamination is present on the central portion of the Property near the location of an abandoned heating oil UST. Concentrations of lead in two soil samples collected in the vicinity of the abandoned heating oil UST exceed IEPA TACO Tier 1 SROs.

The historical data indicate high levels of contaminants within the targeted areas (e.g., clay pit or heating oil underground storage tank). Due to financial limitations, which are common with such actual filed projects, the list of selected contaminants is not exhaustive; nonetheless the selected COCs are likely to be the most detrimental to human health (i.e., trichloroethylene, mercury, and lead) and the measures taken to remedy their presence will remedy the presence of all the others as well.

4. Selected Containments of Concern

The Property under investigation is currently vacant. On this area there was a facility which was historically used as a manufacturing facility and within the boundaries of this area there was never a residential development. Due to the site currently being vacant, the only two potential exposed populations in the foreseeable future will be construction workers redeveloping the site and recreational (trespassing) people. It should also be noted that groundwater is not a factor because the facility was historically connected to a large metropolitan water distribution system.

The Occupational Safety and Health Administration (OSHA) has established permissible exposure limits (PEL). PEL are legal limits for exposure of an employee to a chemical substance. A PEL is usually given as a time-weighted average (TWA). A TWA is the average exposure over a specified period of time, usually a nominal eight hours. For the COCs in this study: Trichloroethylene: Construction Industry is 100 ppm TWA (29 CFR 1926.55); Mercury: General Industry is 0.1 mg/m3 TWA (29 CFR 1910.100); Lead: Construction Industry is 0.05 mg/m3 TWA (29 CFR 1926.62). It should be noted that OSHA limits generally are not as conservative as those established by the IEPA and USEPA

A Conceptual Site Model is an explanation of how contaminants arrive into a system and are transported within the system, and potential routes of exposure to humans (USEPA, 1996). It provides a structure for evaluating risks from contaminants, establishing remedial strategies, defining source controls, and how to address unacceptable risks (USEPA, 1996). The historical site investigations introduced and addressed various CSM components for the Property and were conducted in targeted areas (e.g. former clay pit and UST); however, this did not allow investigators to establish proper spatial boundaries of the COCs. The scope for this CSM, and the focus for most of the fate, transport, and exposure evaluations (Table I)

Table 1. Conceptual Site Model

Source	Environmental Exposure Media	Exposure Point	Exposure Route	Exposed Population
Industrial Area	Soil	Subsurface Construction	Inhalation of Particulates	Construction Workers
Industrial Area	Soil	West side of Property near River	Inhalation of Particulates	Recreational Persons

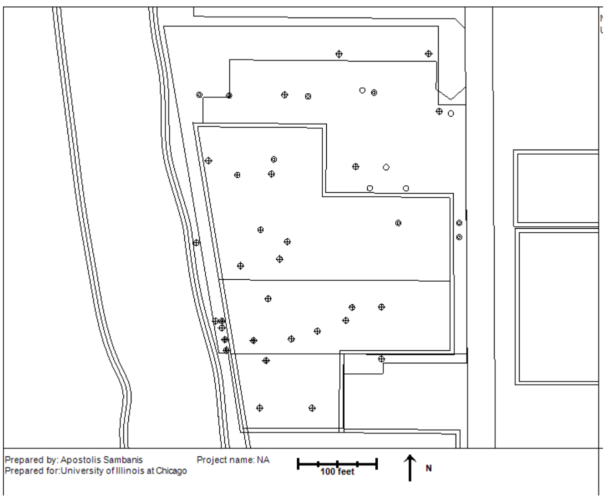

Figure 1. Site Location Map showing historical soil sampling point

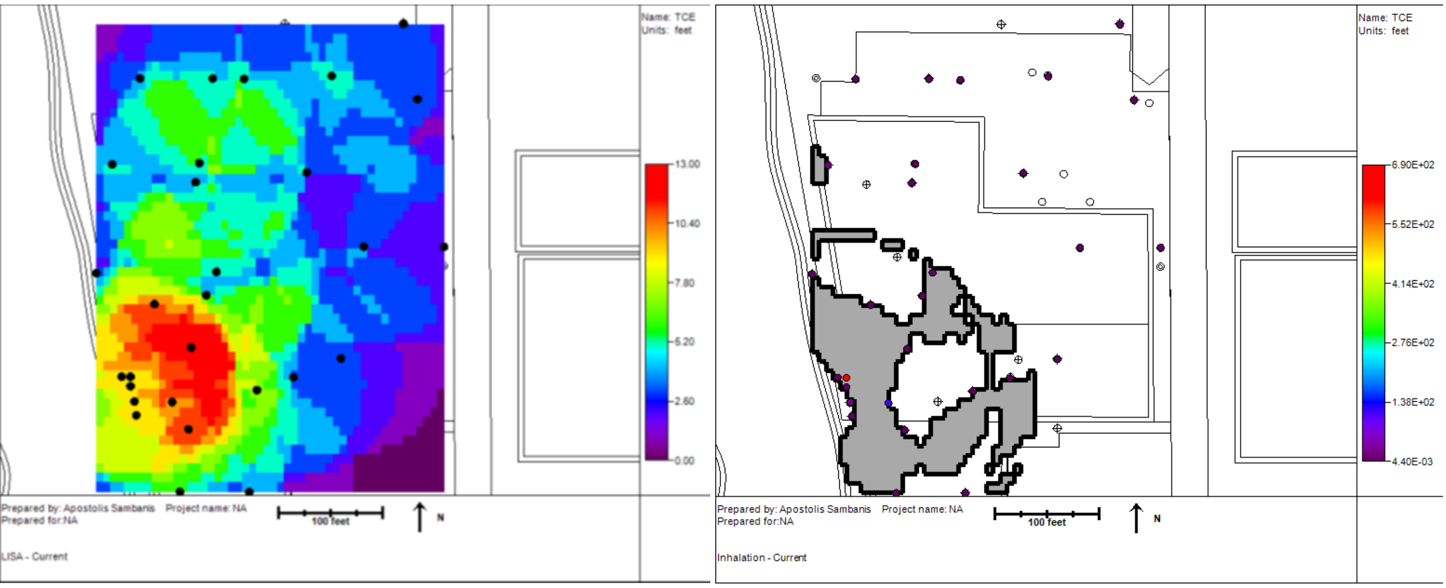

Figure 2. Hot Spot Map (left) and Construction Worker Restriction Zone (right) Generated for TCE

5. General Input Values

A construction worker and a trespassing recreational person at the site may be exposed to contaminated soil if the approximately 1-foot top layer of soil at the site is somehow breached during normal activity. Any recreational exposure is anticipated to be of short duration, as it would be the result of trespassing on the site for a short duration and a child is assumed to be conservative due to their established limits and threshold are much lower than adults. Both populations are therefore assumed exposed to COCs in soil due to incidental inhalation of respirable particulates. It should be noted, according to USEPA guidance, the construction worker scenario is usually described as a short-term adult receptor who is exposed to soil contaminants during the work day for the duration of a single construction project (typically a year or less) (USEPA, 2001a). If multiple non-concurrent construction projects are anticipated, it is assumed that different workers will be employed for each project. The activities for this receptor typically involve substantial on-site exposures to surface and subsurface soils. Trichloroethylene, lead, and mercury are considered to be non-radionuclides; and thus the risk based equation within SADA was used when determining our soil inhalation intake for the construction worker and recreational person scenarios. The construction worker population is assumed to comprise adults with a body weight of 70 kg (USEPA, 1991), an inhalation rate of 20 m^3/8 hr-day for moderate activity (USEPA, 2001a), and an exposure duration of one year, with an exposure frequency of 225 days per year. A child under the recreational scenario is assumed to have an average body weight of 30 kg, be exposed for 6 years, and have an exposure frequency of 30 days per year (USEPA, 2001a). An evaluation was conducted using the risk based equations provided by SADA. It utilized the method developed by USEPA to estimate the permissible risk levels associated with the cleanup of contaminated soils to assess potential risks to construction workers and recreational persons while on-site potentially exposed to contaminated subsurface soils (USEPA, 1991). This method provides for an assessment of overall risk combining contributions resulting from incidental inhalation.

For brownfield assessments, the concentration term in the intake equation is an estimate of the arithmetic average concentration for a contaminant based on a set of site sampling results. According to USEPA, because of the uncertainty associated with estimating the true average concentration at a site, the 95% upper confidence limit (UCL) of the arithmetic mean should be used for this variable (USEPA 1996). The 95% UCL provides reasonable confidence that the true site average will not be underestimated. Based on the results, the SADA exposure statistics were adjusted by the appropriate UCL thus using the representative soil concentration value for each COC and allowing calculation of the maximum soil intake for each scenario. The model was calibrated and distribution choices made for each contaminant; we calculated potential high risk areas in a brownfield site with the objective of protecting construction workers and recreational persons. Based on these criteria, concentrations exist on the Property that exceed the IEPA TACO Tier 1 Construction Worker Scenario Inhalation route SROs. To calculate high risk areas, SADA uses ordinary kriging. Instead of weighting nearby data points by some power of their inverted distance, ordinary kriging relies on the spatial correlation structure of the data to determine the weighting values. This is a more rigorous approach to modeling, as correlation between data points determines the estimated value at an unsampled point. The resulting high risk area maps serve as an important foundation for decision frameworks that determine cost and boundaries for the remedial process. Our high risk areas based on the historical investigation data had multiple unestimated points with no clear boundaries. The high risk areas based on SADA display clear boundaries.

6. Hot Spot Evaluation

Local Indicators of Spatial Association (LISA) provide information on types of spatial association at the local level. LISA maps indicate the presence or absences of significant spatial clusters or outliers for each sample location. LISA maps were particularly useful in identifying local hot spots located on the Property. LISA maps based on historical data show limited hot spot concentrations of the COCs. An example of a hot spot map for TCE generate for the site located on the southwest corner of the site is shown in Figure 2.

7. Worker Restrictive Zones

After determination of both the high risk areas and hot spots of the COCs, a need to regulate the worker restrictive zones was evident. Performing construction in areas of known site contamination can significantly increase project costs and construction worker exposure. If soil is excavated to the depths within these high risk areas, it will increase the probability of encountering contamination during construction and may require follow-up environmental investigation and reporting.

Using SADA, we identified high risk areas of contamination and clean up restrictive zones for construction workers excavating in those areas were established (an example for TCE is displayed in Figure 3). Consistent with hazardous waste operations, there was a legal obligation to inform construction workers about the nature and level of hazardous substances at this site, and likely degree of exposure to workers who participate in site operations (Allan *et al*., 1996). Thus, the purpose of characterization and creation of restrictive zones is to identify and quantify the health and safety hazards associated with each site task and operation, and stream lines with the legal obligations of each interested party (USEPA, 2001b). Risks are then eliminated if possible, or effectively controlled: Construction workers working within the gray areas will be required to wear respirators with the appropriate cartridge based on the COC to minimize their potential exposure. The development of restrictive zones, based on high risk areas identified by SADA, is extremely useful for developing site safety plans and helps increase efficiency by prioritizing clean-up operations in brownfield redevelopment.

8. Limitations of Study

Site characterization, assessment of potential exposures, assessment of the toxicity of specific chemicals, and the characterization of risk are all in some respects uncertain. In characterizing a contaminated site, it is not possible to know with certainty the concentration of contaminants of concern at all locations. The characterization of any site involves the collection and analysis of soil or other samples that are of small volume compared with the overall site. Concentrations in unsampled areas may vary. Methods used to increase the accuracy of site characterization usually include the selection of samples exhibiting the greatest qualitative indications of contamination, or the intentional collection of samples from areas where concentrations are expected to be the highest. In this study, the uncertainty of site characterization is countered by utilizing the highest concentrations for each contaminant of concern that was detected in the various samples collected at the site.

9. Conclusions

The results of the study point to the usefulness of the software as it applies to public health, as specifically borne out by our being able to achieve the study objectives. The SADA software was able to compare to human health risk component and determine high risk areas based on construction worker land uses. The data captured from the SADA site investigation was useful in identifying hot spots of contaminants of concern and creating worker restrictive zones. Thus, SADA was shown to have utility for a range of public and private applications, and is appropriate for planning brownfield redevelopment.

References

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, Pub. L. No. 96-510, 94 Stat. 2767. 1980.

Knowlton, Robert G. and Minier, Jeffrie (2001), Recent Trend for Environmental Compliance Provides New Opportunities for Land and Water Use at Brownfields and Other Contaminated Sites. N*atural Resources Journal*, **41**, No. 4. 2001.

Illinois Environmental Protection Agency. Title 35: Environmental Protection. Subtitle G: Waste Disposal, Chapter I: Pollution Control Board, Part 742: Tiered Approach to Corrective Action Objectives. Illinois Statutes, Springfield, IL. 1997.

Layman, R.H. and Northrup C.J. Survey of Illinois Law: Environment; 22 S. Ill. U. L. J. 879. 1998.

Murphy M. The Impact of Superfund and Other Environmental Statutes on Commercial Lending and Investment Activities. 41 Bus. Law. 1133. 1986.

Powell, Frona M. Amending CERCLA to Encourage the Redevelopment of Brownfields: Issues, Concerns, and Recommendations; 53 Wash. U. J. Urb. & Contemp. L. 113. 1998.

Schenck, D. The Next Step for Brownfields: Government Reinsurance of Environmental Cleanup Policies. Connecticut Insurance Law Journal, 10: 2004.

Spatial Analysis and Decision Assistance. University of Tennessee, United States. Available via http://www.tiem.utk.edu/~sada/. Cited January 13, 2008.

Simon W.H. The Community Economic Development Movement: Law, Business, and the New Social Policy. pp 1-6. 2001.

U.S. Environmental Protection Agency. Risk assessment guidance for Superfund volume I: human health evaluation manual (Part A). EPA/540/1-89/002. U.S. Environmental Protection Agency, Washington, DC 20460: 1989.

U.S. Environmental Protection Agency. Role of the baseline risk assessment in superfund remedy selection decisions. OSWER 9355.0-30. Office of Emergency and Remedial Response. U.S. Environmental Protection Agency, Washington, DC 20460: 1991.

U.S. Environmental Protection Agency. Soil screening guidance: technical background document. Office of Solid Waste and Emergency Response. U.S. Environmental Protection Agency, Washington, DC 20460: 1996.

U.S. Environmental Protection Agency. Lead; identification of dangerous levels of lead; final rule. (40 CFR Part 745). Washington DC: 2001a.

U.S. Environmental Protection Agency. Risk assessment guidance for superfund: volume 1 human health evaluation manual (part d, standardized planning, reporting, and review of superfund risk assessments. Publication 9285.7-47. Office of Emergency and Remedial Response. U.S. Environmental Protection Agency, Washington, DC 20460: 2001b.

U.S. Environmental Protection Agency. Mid-atlantic risk assessment user's guide. Retrieved from http://www.epa.gov/reg3hwmd/risk/human/rbconcentration_table/usersguide.htm January 1, 2011.