Environmental Modelling & Software 26 (2011) 751–760

Contents lists available at ScienceDirect

Environmental Modelling & Software

journal homepage: www.elsevier.com/locate/envsoft

An environmental decision support system for spatial assessment and selective remediation

Robert N. Stewart [a,b], S. Thomas Purucker [c,*]

[a] Department of Ecology and Evolutionary Biology, University of Tennessee, Knoxville, TN 37996, USA
[b] Computational Sciences and Engineering Division, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831, USA
[c] Office of Research and Development, U.S. Environmental Protection Agency, 960 College Station Road, Athens, GA 30605, USA

A R T I C L E I N F O

Article history:
Received 21 April 2010
Received in revised form
20 December 2010
Accepted 23 December 2010
Available online 3 February 2011

Keywords:
Environmental decision support software
Geostatistics
Sample design
Risk assessment
Selective remediation

A B S T R A C T

Spatial Analysis and Decision Assistance (SADA) is a Windows freeware program that incorporates spatial assessment tools for effective environmental remediation. The software integrates modules for GIS, visualization, geospatial analysis, statistical analysis, human health and ecological risk assessment, cost/benefit analysis, sampling design, and decision support. SADA began as a simple tool for integrating risk assessment with spatial modeling tools. It has since evolved into a freeware product primarily targeted for spatial site investigation and soil remediation design, though its applications have extended into many diverse environmental disciplines that emphasize the spatial distribution of data. Because of the variety of algorithms incorporated, the user interface is engineered in a consistent and scalable manner to expose additional functionality without a burdensome increase in complexity. The scalable environment permits it to be used for both application and research goals, especially investigating spatial aspects important for estimating environmental exposures and designing efficient remedial designs. The result is a mature infrastructure with considerable environmental decision support capabilities. We provide an overview of SADA's central functions and discuss how the problem of integrating diverse models in a tractable manner was addressed.

Published by Elsevier Ltd.

Software availability

SADA is freeware: binaries for the full-featured installation files, documentation, databases, and examples are available for free download at: http://www.tiem.utk.edu/~sada/index.shtml. Minimum resolution is 1024 × 768 with 16 million colors (for 3-D viewing); processor should be a minimum Pentium 3 processor with 800 GHz, 512 MB RAM, and 800 MB hard disk space available for installation. The interface is constructed in VB.Net and leverages dynamic link libraries for algorithms constructed in other languages, including C and Fortran.

1. Introduction

Visualization is a key component of modern site assessments; however, visualization combined with spatial data analysis and assessment algorithms requires programming skills and budgets not always available for site assessments. These assessments require the integrated use of tools from multiple disciplines; including Geographic Information Systems (GIS), sample design, statistics, data management, two- and three-dimensional visualization, spatial modeling, uncertainty analysis, risk assessment, remedial design, and cost/benefit analysis. These diverse capabilities must then be used together in a coherent, defensible, repeatable decision process (Matott et al., 2009). Generally, this algorithmic integration is achieved through highly flexible implementations that require significant programming capability (e.g., command-line interface of *R* with contributed packages (R Development Core Team, 2010); plug and play model capabilities of FRAMES (Babendreier and Castleton, 2005)), proprietary software that may require significant financial resources and add functionality in response to market demand (ESRI), or even a sequence of individual models to handle each component separately. This situation creates a gap in software availability, decision support freeware for environmental assessment practitioners that does not require a significant investment in training and/or finances to apply at contaminated sites.

Spatial Analysis and Decision Assistance (SADA) is freeware that fills this gap. It has been developed at the University of Tennessee's Institute for Environmental Modeling in collaboration with other

* Corresponding author.
E-mail address: purucker.tom@gmail.com (S.T. Purucker).

1364-8152/$ – see front matter Published by Elsevier Ltd.
doi:10.1016/j.envsoft.2010.12.010

Universities, federal agencies, national laboratories, private sector companies, and individual consultants. The software has been funded by the U.S. Nuclear Regulatory Commission (USNRC), U.S. Environmental Protection Agency (USEPA), and the U.S. Department of Energy (USDOE). SADA has been in development for over a decade with its most recent release (Version 5.0) in 2009. Past versions have generated world-wide interest, over 20,000 downloads from 100+ countries, with the majority of users in North America and Europe. The software provides a tool that makes a direct, practical connection between data analysis, modeling, and decision-making within a spatial context (Stewart and Purucker, 2006). The target user is an environmental investigator interested in characterizing contamination for a particular site and designing selective remedial actions.

SADA has been used in a number of environmental modeling applications – including site assessments, academic investigations, and regulatory frameworks designed to streamline characterization processes. Direct application of the software, or discussion of its role in environmental investigations have appeared in a number of peer-reviewed articles. These include the assessment of contaminated sites such as underground storage tanks; landfill disposal sites (Butt et al., 2008a,b); contaminated land (Bardos et al., 2001; Carlon et al., 2007; Chung et al. 2007); surface water (Boillot et al., 2008); groundwater (Hornbruch et al., 2009); floodplains (Sauer et al., 2007); and applied spatial analyses for all these media (Goovaerts, 2010). Broader applications include investigations of microbial community structure (Franklin and Mills, 2003) and enzyme activity (Smart and Jackson, 2009); multi-criteria decision analyses (Linkov et al., 2004); boundary delineation of soil polygons for terrain analysis (Sunila et al., 2004); disease incidence (Ifatimehin and Ogbe, 2008); examination of interactions between habitat and contamination on ecological dose (Purucker et al., 2007); soil remediation frameworks (Norrman et al., 2008; Rügner et al., 2006); hot spot delineation (Sinha et al., 2007); landscape ecology (Purucker et al., 2009b; Steiniger and Hay, 2009); human health risk (Andam et al., 2007); and determining laboratory analytical support necessary to support field-level data collection (Puckett and Shaw, 2005).

In addition, SADA capabilities as an environmental management computational toolkit (Holland et al., 2003) have led its adoption within regulatory frameworks. Principal among these are the USEPA's Triad approach (Crumbling, 2001) and the USNRC's Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM). The USEPA has long recommended SADA as a tool for strategic site investigation and characterization (U.S. Environmental Protection Agency (USEPA), 2001a, 2005a, 2005b); however, recent developments in the Triad approach, a consensus-based decision-making approach for hazardous waste sites that maximizes use of innovative characterization tools and strategies (Crumbling et al., 2003), have increased its utility for larger-scale applications.

Construction of this type of software provides numerous opportunities for application and research. As a vehicle for deploying existing methods and developing new assessment approaches, SADA must meet several, sometimes conflicting, objectives successfully. A critical factor is the user interface. It is important to engineer an assessment environment that encompasses needed functionality, yet is also suited to specific users with specific goals. These objectives are met by a scalable interface that is visually consistent while providing access to the depth of available algorithms. The interface was created with four criteria in mind: (1) users should easily find an achievable assessment goal; (2) the interface should present only relevant tool sets and not clutter the computational environment; (3) the interface should provide open, flexible guidance through any interim steps required to achieve the assessment goal; and (4) the interface should be consistent across all goals. The primary modules and functions that help meet these criteria are encapsulated as objects that can be accessed for various decision-informing outputs (Rizzoli and Davis, 1999). For any given modeling task, the interface presents only the required steps and functional elements for that task; these methods range from simple statistical output to risk-based area of concern (AOC) maps based on ecological exposure models and geostatistical algorithms.

This manuscript describes the primary environmental assessment methods that are incorporated into the software, then presents the results of the integration with a focus on how the decision elements were accommodated into the interface, and a discussion concerning the elements of the scalable decision interface that both allows for added functionality in a scalable manner and guides the user through complicated, multi-step decision processes.

2. Methods

SADA's basic tool set encompasses many areas of environmental characterization and assessment. Fig. 1 shows how these tools are typically organized to facilitate decision support from the earliest phases of an investigation. In the following text, we briefly summarize available methods for: determining the number of samples needed to characterize a site; creating sample designs; data management; exploratory data analysis; and spatial modeling tools.

2.1. Sample design

Sampling is imperfect and subject to error (Christakos and Olea, 1992); uncertainty sources include the complex and dynamic processes under study, economic realities, and the technical limitations of available sampling and analytical methods (Thompson, 1999). Short of exhaustive sampling, investigators must use a limited set of data and accept uncertainty to characterize conditions at a site. An early decision when characterizing contaminated sites is determining how many samples to collect. For smaller sites this is often a function of the available sampling budget; however, statistical power curve methods recommended by the U.S. Environmental Protection Agency (USEPA) (2000, 2006) can be used to estimate sample sizes required to support decisions with specified error rates. SADA uses power curves based on the non-parametric Sign and Wilcoxon rank sum tests from MARSSIM guidance (Gogolak et al., 1998) and algorithms implemented in Gogolak (2001) to calculate required sample sizes and display power curves. Implementation requires specifying alpha and beta decision errors, a target concentration for the alpha decision error, a lower bound for the beta decision error, and an estimate of the standard deviation. After the data has been collected, a retrospective power curve can be constructed using the number of samples actually collected and the observed standard deviation to ensure that decision objectives were satisfied.

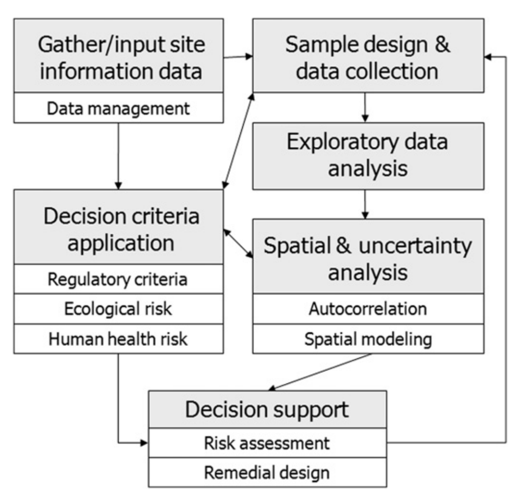

Fig. 1. Primary components of the graphical user interface that contain SADA software functions and a typical example flow path. Different chart elements are supported by decision support interview processes that guide the user through the relevant steps. The scalable and object-oriented nature of the components allows for new functions to be added to the software in a consistent manner and for existing modules to be recombined in useful ways, with new interview processes, to provide support for a range of decision support processes. Although environmental assessment decision processes are usually considered to be acyclic, decision support software must facilitate the ability to revisit earlier steps with update information. The presented components correspond to subheadings in the methods and results text.