Applying GIS to Hazardous Materials Site Management

Prior to modern day environmental laws, properties were managed with little control or concern for the protection of the environment. As such, historic uses, industrial processes, commercial activities, careless waste management practices, and uncontrolled disposal lead to soil and groundwater contamination. The wide range of contaminants are grouped under the umbrella term “hazardous materials.” In the United States, hazardous materials have many regulatory definitions that are dependent on the jurisdiction of the regulating agency (i.e. U.S. Environmental Protection Agency, U.S. Dept. of Transportation, etc.). For the purposes of this project, hazardous materials shall mean any substance or material that poses risk to public health or welfare and/or the environment. Knowing the locations and understanding the extent of contamination of a property (also referred to as “site”) is vital information for land planners, environmental managers, decision makers, or risk assessors. Geographic Information System (GIS) software is a valuable resource for entering, editing, storing, manipulating, and displaying geographically referenced data. GIS can be easily integrated into hazardous materials site management.

Understanding the location and extent of contamination on a site is important for land conservation, restoration, redevelopment, and planning. Land planners, environmental managers, decision makers, or risk assessors must understand the risks posed by the sites they are working on as well as on the abutting or downgradient sites. It is particularly important at the local and regional planning levels because wise and ethical decision making will affect environmental management and the protection of public health. The goal is to mitigate the risks presented by contamination and to promote the beneficial use or re-use of land.

The literature review methods for this project consisted of searching for and reading peer reviewed research articles from a variety of scholarly journals. The University of Rhode Island’s Library searchable databases (Science Direct, Scopus, and Web of Science) as well as Google Scholar were utilized for locating journal articles. The articles were written by academic researchers or government employees. The case studies discussed in the articles were from projects around the world, including China, England, India, Italy, the Netherlands, Sierra Leone, Turkey, and United States. The authors applied GIS in their research to generate detailed maps, analyze raster and vector data sets, calculate data, interpolate, and model. The general goals of all the researchers were to assist local, regional, and governmental officials in their decision making regarding how to manage existing contaminated land as well as how to safely develop future hazardous material sites such as landfills and hazardous waste treatment facilities.

The researchers’ objectives varied depending on the problem they were attempting to study or remedy. Risk assessments were conducted to evaluate public health and the environment. The concentrations, locations, and extent of contaminated soil and groundwater were analyzed or estimated. Environmental degradation caused by rapid industrialization was assessed. Siting future locations of landfills in ways that protected the health of the local populations was studied. GIS was applied in all scenarios to provide useful data and mapping to aid local, state, federal, and ministry level planners and decision makers.
The researchers utilized several different sets of local, regional, state-wide, and/or country-wide data. Available soil and groundwater sampling data were used for a variety of applications. Existing landfill location data were used in mapping. Environmental data derived from questionnaire surveys of local experts and stakeholders were collected and used. Risk assessment data were widely utilized to make predictions. Census data were utilized in mapping. Local zoning, land use, land cover, infrastructure, and utilities data were overlaid into maps.

The flexibility of GIS, allowed for it to be incorporated into each study and offer a myriad of applications. Analyses were performed on vector and raster data sets. Data sets were queried for information and mapping. Data were overlaid to combine characteristics. Grid math was used to identify spatial patterns and relationships. Interpolation methods, including Inverse Distance Weighting and Kriging, were used to identify data gaps and make predictions. Models of raster and vector data were used to illustrate existing conditions and to assist in future planning. The most common use of GIS in the studies was to produce a variety of map products that visually represented geospatial data.

A key element of managing contaminated sites is evaluating and understanding the risk. Risk assessors are experienced in using available data, analyzing it, manipulating it, comparing it to established public health or environmental standards, and interpreting the results. GIS’s mathematical analysis tools are widely utilized for ranking risk data. The analyzed geospatial data is depicted on desired maps, providing visual images of the threats. GIS allowed for risk assessors to make real time decision.

The most widely used data sets for managing these sites are soil and groundwater sampling data. Sampling environmental media is the primary method to establish the existing conditions of a site. Sampling design is driven by the desired end result. It could be a small scale sampling event for one property, successive sampling events on the same property, a regional scale sampling program, etc. These data sets, along with the physical location of samples (i.e., Latitude and Longitude, Universal Transverse Mercator, or State Plane Coordinates), are easily combined and represented geospatially by GIS.

Both raster and vector data models were used extensively in all case studies. Raster data models were used to show contaminant concentrations. This type of modeling was useful for planning and risk assessments. Continuous surface raster models were used to predict contamination. Raster data sets were helpful in mapping land cover, wetlands, water bodies, and sensitive receptor species. Raster data models were used to find the likelihood of encountering illegal landfills and abandoned contaminated sites. Finally, raster data models were used to depict historic changes in landscapes and site usage.

Vector data modeling consisted of applications involving points, lines, and polygons. Vector data models were used for soil and groundwater sampling locations. Vector data modeling utilized existing infrastructure (i.e. roads, utilities, etc.), building foot prints, land parcel boundaries, and census data. Finally, natural resource features, such as rivers and streams, were mapped using vector models.

GIS proved to be a very powerful tool for risk assessors, planners, environmental managers, and decision makers working with hazardous materials sites. GIS was able to compile, integrate, organize, and overlay multiple vector and raster data sets. Once the data were entered, it could be calculated,
interpolated, or mapped base on the desired end result or product. The data analysis was particularly useful in showing trends and correlations. It proved to be an invaluable tool for risk assessors. Risk assessors used GIS to analyze contamination data, and then calculate threats to public health and the environment. Geospatial data was visually represented through mapping. The maps gave planners and decision makers real time information and a simplified method to organize and view the data. Raster and vector data models were used to make projections for future planning. Models simplified and allowed for consistent management of Brownfields sites and siting future landfills or hazardous waste treatment facilities.

The research for this project concludes that GIS is a well suited application for the management of hazardous material sites. It is flexible and robust for use in risk assessment, planning, and decision making. GIS is clearly a power tool for the management of hazardous material sites, protecting the environment as well as safeguarding public health.
Annotated Bibliography


Contaminated sites present risks to human health and the environment and the problem has resulted in risk assessments being used in land management approaches. Academic researchers from the Netherlands developed a Health Index/Risk Evaluation Tool (HIRET) to integrate risk assessment and spatial planning through GIS. Risk assessment is typically used in land-management to estimate the threats, establish the priority of remediation, set generic or specific remedial goals, and predict any residual risks after partial remediation activities. There are many factors that influence functional changes of a contaminated site. Therefore, a long-term approach is needed to ensure that the current land management decisions made are appropriate for future uses of the land. Their research used a HIRET methodology to combine the human health risk assessment procedure with spatial and temporal information. The HIRET methodology was applied to a site that was contaminated with benzene and had industrial, recreational, and residential areas. They used GIS to map current and future land use, calculate human health risks, present differences between human health risks with respect to land use, and predict the extent of contamination from existing conditions to 50 years into the future. The study showed that differences in land use demonstrated obvious differences to human exposure and potential health risks. Considering actual and anticipated future land use in risk assessments can prove valuable for environmental decision making, and planning will ultimately reduce risk in a cost effective way. This was the best article that I read because the discussion clearly showed how GIS generated easily identifiable mapping that could be used by planners and managers to protect human health.


A group of Italian researchers studied the probability of finding illegal landfills in the Veneto Region of Italy on the behalf of government authorities. Identifying waste disposal sites is a complex spatial problem and can be solved through the use of spatial analysis models. Multi-criteria evaluation (MCE) methods are used by environmental planners to examine the impacts of proposed new land uses and to compare different development scenarios. They combined GIS with MCE and multi-factor evaluation in this research. Local authorities and the military provided data from the Veneto Region for the study. Spatial criteria data included locations of quarries, authorized landfills, and industrial sites, while spatial factor data included road network accessibility, population density, and land cover. Siting factors and criteria were used to construct multiple suitability index maps of the study area that were overlaid using GIS to create one final suitability map. The suitability index for each map was used in a spatial statistical analysis to calculate the conditional probability of the presence of an illegal landfill in the region. The analysis resulted in the creation of a single complete database of quarries and landfills in the region that could be used for the quantitative study of correlated themed data. Environmental managers could use the database to determine the probability of the locations of illegal landfills. It was
beneficial to see the researchers’ application of Grid Math in GIS to calculate the probability of the suitability index maps.


A group of Italian researchers from the University Cà Foscari in Venice and Thetis worked on a spatial risk assessment project funded by the Italian Ministry of University and Scientific Research. They used the Spatial Decision Support System (SDSS) referred to as DESYRE in their research. The software generates spatial risk assessments which are used to select remediation technologies and create remediation plans. DESYRE works well on large contaminated sites, referred to by the authors as “megasites.” The objectives of remediating contaminated soil and groundwater are to reduce environmental risk to acceptable levels and allow for contaminated properties to be reused and redeveloped. Risk reduction approaches are influenced by spatial priorities, temporal scales, sensitive receptors, and the selection of the most appropriate remedial technologies. A case study example of the Porto Marghera megasite in Venice, Italy described how the GIS software was used to create a remediation plan for the site which had been contaminated by historical industrial activity. The software was able to apply geostatistical interpolation to map the distribution of the contaminants of concern, which proved valuable for the exposure assessment. In addition, it provided zoning of the site through the creation of risk distribution vector maps for contaminants of concerns and exposure pathways. The DESYRE software was found to have spatial variability limitations. However, the framework presented in the study could be used with other GIS tools. It was interesting to learn how contaminated sites are managed in Italy and there are many similarities related to site remediation projects in the United States.


Gay and Korre’s article presented a newly developed, spatially evaluated quantitative risk assessment methodology. Their research focused on assessing risks to human health posed by exposure to contaminated soil. Contaminated land, often contaminated by past industrial uses or waste management practices, presents a human health risk in many countries. Their study focused on analyzing data of human intakes of arsenic from soil which were collected by the British Geological Survey, and mapped it using GIS to identify trends. The soil sampling data originated from Stoke on Trent, an urban, industrial region of the United Kingdom. GIS was used to run simulations of the number
of people with intakes of high levels of arsenic from soil as well as how many people and in which areas were at risk. The GIS mapping showed that the new method was an improvement on previous methodology, and it provided an important “snapshot” of the risk of the exposed human population. Overall, Gay and Korre conducted a logical and well written article that shed light on an international problem.


In this article a group of Chinese state and academic researchers examined the problem that human pressures were causing the rapid degradation and destruction of China’s environment. Their rapid industrialization over the past three decades has resulted in many environmental problems including; the decline of forest and grasslands, accelerated desertification, soil erosion, water loss, degradation of water quality, pollution, food safety threats, the rise of invasive species, dramatic reduction of biodiversity, etc. A Regional Risk Assessment (RRA) approach was used to rank risks in terms of magnitude to show how industrial impacts adversely affected receptors in a region. The objective of their research was to develop an integrated methodology for RRA that supported local decision makers by helping them identify environmentally suitable industrial siting practices that reduce risks to human health and the environment as well as improve socio-economic conditions. A case study applied the methodology to the Chinese region of Hulunbeier which was under rapid industrial growth and economic development since 2002. Elements of the study included a vulnerability analysis to score local receptors, a pathway relevance analysis to estimate pathway relevance scores, and a socio-economic assessment to rank local administrative units by economic development potential. GIS was used to identify risk factors, assign spatial attributes to each receptor, allocate pathway relevance scores, and create maps of the spatial distribution values. It was concluded that the methodology provided a holistic and flexible approach for local planners to evaluate environmental and socio-economic conditions in changing regions of China. It was an interesting risk assessment approach to address China’s rapid industrialization problems. Based on the positive response from local planning officials, it seems likely to be a useful risk assessment tool for that country.


Samanlioglu’s research entailed the use of a mathematical model to address the problem of the industrial hazardous waste location-routing. Management of hazardous materials (hazmat) entails collection, transportation, treatment, recycling, and disposal of chemical and chemical wastes. There is a worldwide trend of increased development in technology and industry which is leading to the generation of more hazmat. More structured and scientific management of hazmat is needed. The case
study applied the mathematical model that was developed in the research to 20 districts in the Marmara region of Turkey based on the likelihood of generating hazmat and they were assumed to be suitable locations for treatment, disposal, and recycling centers. GIS was used in the research to analyze highway network, administrative districts, and population information. The formula developed was computed using software, and several different formulations scenarios were run. The formula was deemed adequate for infrequent decision making scenarios; however, to solve the bigger problem in a shorter time it was recommended that future research was needed. The research was interesting, but I found the calculation discussion sections difficult to follow. It put into perspective how managing hazmat in the age of rapid industrialization worldwide is challenging.


Thomas’ research entailed building a prototype Brownfields site decision support system that could be used by local officials in their siting decisions. The U.S. Environmental Protection Agency defines a Brownfields site as an abandoned, idle, or under-used industrial and commercial property where expansion or redevelopment is complicated by real or perceived environmental contamination. City governments see the importance of these sites for sustainable land use, urban revitalization, and tax revenue. However, Brownfields sites had adopted a stigma of being risky properties due to the contamination and not cost effective for redevelopment. GIS was a critical aspect to augment Thomas’ system. The system used available local, state, and regional geospatial data; web-based tools available to inventory Brownfields sites; GIS models for visualization and decision criteria; and public interaction, training, and outreach. The system was applied through a case study of Jackson County, Michigan which at that time was experiencing rapid economic and population growth. GIS was used to evaluate project objectives, compare siting alternatives, assess the effects of proposed redevelopment projects, rank known Brownfields sites, estimate land use impacts, run scenarios from compiled data, and generate maps for decision making. Local government, community, and business leaders as well as members of the public were engaged for the case study. I could relate to this article because I have worked on several Brownfields sites throughout my career and I recognize the importance of applying GIS to the decision making process.