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A streamlined risk screening method for managing reutilization of abandoned factories in Taiwan

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ABSTRACT

An integrated management strategy that considers the competing relationships between land values and associated risks in the process of land-use conversion is needed to assess and manage the reutilization of brownfields. However, the often large number of individual brownfields renders it difficult to conduct a completed risk assessment for all sites, and a streamlined risk screening method would facilitate prioritization of the redevelopment of those factories. This methodology takes into account the spatial heterogeneity of contaminated lands and produces risk mapping that compiles complex risk-related information. Using abandoned factories in Taiwan as a case study, the method considers 40 points (50% accumulated probability) as the threshold of acceptable risk. Emergency risk should be over 90% of accumulated probability. For the sustainability of brownfield reutilization in Taiwan, this research uses a risk matrix to identify the low, middle, and high risk for brownfield reutilization. It can indicate zones with a high risk level or low economic incentive as areas of concern for future decision making. In Taiwan, high-risk sites with high incentive account for only 21.3% of the sites. In contrast, the sites with the lowest incentive and low risk account for 57.6% of the sites. To avoid failure in the brownfield market, three strategies are suggested: (1) flexible land management with urban planning is a feasible option for protecting the receptor's health; (2) the government could provide the tool or brownfield funds to reduce the uncertainty of investment risk; and (3) risk monitoring and management can reduce the possible pitfalls associated with brownfield reutilization.

1. Introduction

A large portion of brownfields sites are located in industrial areas. For example, De Sousa [1] determined that 43% of brownfield lands were located in industrial zones and that 25% of them were potentially polluted. An estimation of brownfield reuse in the U.S. indicates that approximately 70% of brownfield reutilization areas were industrial sites, and approximately 5–10% of brownfields are located in urban renewal areas [2]. According to a survey conducted by the Taiwan Environmental Protection Administration (TWEPA), Taiwan has approximately 120,000 abandoned factories that are potentially contaminated; approximately 60% of the land at these factory sites already exceeds the control standards of the Soil and Groundwater Pollution Remediation Act (known as the Remediation Act) [3]. However, there is a lack of management strategies for brownfield redevelopment in Taiwan, and it is difficult to separate the responsibilities of remediation or redevelopment for potentially contaminated sites. In the past, the United States Environmental Protection Agency (USEPA) also faced the same problem. Approximately 10% of 450,000 brownfield reutilization sites are still listed in the National Priorities List, which means that these sites could pose serious hazards to the surrounding environment and people [4]. Therefore, the USEPA has provided guidance and tools, in the form of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), to clarify liability at brownfields and Superfund sites.

Due to the lack of land resources in Taiwan, the rate of converting former industrial sites into other land types is higher than that of other countries. In Taiwan, industrial density is about 2.66 km^{-2}, and mixed use of land increases public health risks after converting to other land types from abandoned factories. However, the government did not clearly define environmental risks and

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redevelopment incentives, resulting in a lack of management in identifying reuse strategies for potentially contaminated sites. To address this problem, beginning in 2004, the government of Taiwan has focused on the problems of abandoned factories. A large database contains information about past operating conditions, land types, soil and groundwater environment, and human behaviour during the past ten years [5]. In the past, risk-based management for contaminated sites was complex and considered site-specific factors verifying the transport and fate of pollutants. In addition, exposure pathways of different groups via contaminated media depended on the receptor's behaviour. An integrated management strategy that considers the competing relationships between land values and associated risks in the process of land-use conversion is needed.

Development of a simplified risk screening assessment is a major challenge, since environmental and exposure conditions vary spatially. In Europe, the simple risk-screening concept includes the proposed source, pathway and receptor decision-making tools to determine brownfield reutilization management strategies [6]. In addition, the EU has considered both sustainable land use and urban development in terms of economics and policy to establish a primary risk assessment model [7]. Thus, risk-screening maps can indicate which risk level should serve as a reference for decision making. Furthermore, CERCLA Section 104 established risk management strategies based on information from the toxics release inventory (TRI) for polluted industrial sites [8]. The TRI categories cover not only CERCLA hazardous substances but also other chemicals because of the concept of pollution prevention management from industrial and federal facilities. Risk-screening environmental indicators, combined with the TRI database, can facilitate simple risk-screening management for policy makers, researchers and communities based on the Emergency Planning & Community Right-to-Know Act [8].

A map of risk for various management scenarios would be a more useful tool to delineate the spatial variability of risk-related factors [9]. The spatial characteristics of land influence the values and environmental impacts with brownfield reutilization [10–12]. To facilitate evaluation of the sustainability of contaminated land reutilization, many useful tools and decision-making models have been established [13–16]. Geographic information system (GIS) has been recognized as valuable for land management, health risk, and environmental quality assessments to address regional spatial variability [17–20]. Additional research has classified spatial variability to characterize the vulnerable zone of potential contamination resulting in environmental conditions combing the decision tree and spatial statistics [21–23]. Further, distinct spatial characteristics of various receptor behaviour can be depicted clearly as the basis of exposure pathways [11].

A streamlined risk screening method that incorporates GIS should be helpful in identifying priorities for site redevelopment. A streamlined risk screening method can facilitate the evaluation of management strategies for potentially contaminated land in Taiwan. The purpose of this study is therefore to establish a risk matrix that links the environmental risk factors with various types of land reuse. Based on the land values and risk scores, this research improves the probability of choosing low-risk sites to prioritize reutilization and enhance economic incentives. Moreover, risk screening maps can identify high-risk sites to avoid further reutilization of brownfields before reducing environmental risk.

2. Materials and methods

2.1. Risk matrix of brownfield reutilization

Fig. 1 illustrates the approach to developing the risk matrix that combines the streamlined risk-screening model and evaluating incentive of land reutilization in this study. To evaluate the risk score and set up the principle of screening level, this research considers the theoretical significance of each factor based on traditional risk assessment and intersects pollution attributes of geo-information as reference scores of source, as well as vulnerability maps as reference scores of pathway and receptor. This research considers the three categories of traditional risk assessment, or source, pathways and receptors, and sets up spatial classifications for abandoned factories including past characteristics, environmental geology and receptor lifestyle into a geo-database. Moreover, expert interviews are conducted to establish the weighting of the above indicators to aggregate the risk scores. The total risk for an individual abandoned factory is evaluated, after which three risk screening levels are set up based on the accumulated distributions of all abandoned factories. An acceptable risk score is identified based on 50% of accumulative probability as well as an emergency risk score, which should be over 90% of accumulative probability.

Furthermore, in order to analyse the relationships between land values and associated risks in the process of land-use conversion, this study uses a risk matrix to identify low, middle, and high risk for brownfield reutilization. This research combines the following risk-screening scores: 0–29 points (low risk), 30–39 points (middle risk), and 40–100 points (high risk). The landowner has to pay an incremental tax to avoid the phenomenon of speculation as landowners' income increases when the land increases in value. This principle takes into account three levels of land tax: (1) less than 100% of increased value, (2) 100–200% of increased value, and (3) more than 200% of increased value. To evaluate the land incentive of brownfield reutilization, the present value appreciation rate is categorized according to the three evaluation standards: < 100% (no incentive), 100–200% (potential incentive), and > 200% (obvious incentive). Finally, screening results from the risk matrix can assist in the further management of brownfield reutilization in various cities.

2.2. Streamline risk-screening model

This research takes into account ten factors on source, seven factors on pathway, and three factors combining land use and exposure assessment on receptor. The weights of source, pathways and receptors are 40, 30 and 30%, respectively. Table 1 presents the factor description and weighting for the streamlined risk-screening system. The databases reflect the integration of investigations of abandoned factories from several sources, including TWEPA, IDB, CISP, WRA, CGS, ARI, DGBAS, etc.

The streamlined risk-screening model evaluates the soil and groundwater risk indicators that characterize sources, pathways, and receptors. The source aspect identifies the pollution potential of an individual abandoned factory. The pathway and receptor aspects identify the vulnerability of the environment and receptor; therefore, this research evaluates the vulnerability within 1 km of both aspects of an abandoned factory because of the principles of traditional risk assessment for contaminated sites in Taiwan. The following equations are used to streamline the risk-screening calculations:

$$P_{gw} = \sum [HTP_{gw} \times (A_1 \times B_{gw}) \times (1 + A_4 + A_5) \times (1 + A_{6gw})] \quad (1)$$

$$P_{soil} = \sum [HTP_{soil} \times (A_1 \times B_{soil}) \times (1 + A_4 + A_5) \times (1 + A_{6soil})] \quad (2)$$

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