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Discussion on the Impact Assessment of Hazardous Waste Municipal Environmental Risks under the Concept of "Waste-Free City"

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Abstract: Urban environmental management of hazardous waste is an important aspect of ecological civilization construction and ecological environmental protection, and an important part of winning the battle against pollution. The policy-driven characteristics of hazardous waste environmental management and utilization and disposal determine that institutional innovation should be emphasized in the construction of a "waste-free city." This paper focuses on the environmental risk evaluation of hazardous waste cities, and uses the hierarchical analysis method to carry out empirical analysis using City A as an example. The results show that City A has a "high risk" due to the concentration of chemical and electronic industries, and high hazardous waste disposal volume and release rate. The study proposes to strengthen informationization supervision, implement regional joint prevention and control, improve disposal capacity, and other differentiated control countermeasures, in order to provide scientific support for the fine management of municipal hazardous waste and the construction of "waste-free city," and help to improve the efficiency of hazardous waste treatment and reduce environmental hazards.

Keywords: "Waste-free city" concept; Hazardous waste; Urban environmental risk

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1. Introduction

With the rapid development of China's society and economy, more and more hazardous wastes are generated in many fields and industries, such as industrial sulfuric acid, cyanide, pesticides, medical wastes, and other new chemical products, etc. [1]. These wastes are flammable and explosive, highly corrosive, toxic, and polluting, posing great risks to the environment. According to statistics, the annual generation of hazardous waste in the world has exceeded 4×10^8t. According to the data released by the National Bureau of Statistics, the generation of hazardous waste in China in 2022 reached 95.148 million tons. After preliminary accounting, in 2023, China's hazardous waste generation amounted to about 104.663 million tons. Environmental risks caused by hazardous waste leakage and disposal have occurred many times. In recent years, preventing and resolving environmental risks involving hazardous waste has become an important part of ecological environmental protection work [2]. The CPC Central Committee and the State Council attach great importance to ecological environmental protection and solid waste management, and in December 2018, the State Council issued a pilot program for the construction of "waste-free cities," aiming to deepen the reform of comprehensive solid waste management from the overall level of the city, and exploring the establishment of a system and technology for the construction of "waste-free cities." The aim is to deepen the reform of comprehensive solid waste management from the overall level of cities, explore the establishment of systems, technologies, markets, and regulatory systems towards "waste-free cities," and form a batch of replicable and generalizable demonstration models. Hazardous waste environmental risk prevention and control is one of the six major areas in the construction of a "waste-free city," and its policy-driven characteristics determine that the construction of a "waste-free city" should focus on the issue of institutional innovation [3]. However, there are obvious differences in the level of economic and social development of cities, with different needs for environmental management of hazardous wastes, and environmental risks are the result of the interaction of multiple compound factors such as risk sources, risk receptors, and risk control. Therefore, the results of the standardized assessment do not truly reflect the risk situation in cities, and there is an urgent need to carry out environmental risk assessment based on the economic and social development of cities and the current state of environmental management of hazardous wastes, so as to put forward targeted control measures and governance strategies, and to provide scientific support for the differentiated governance of cities and the refined management of wastes.

2. Overview of hazardous waste

2.1. Source

Hazardous wastes come from a wide range of sources, and are generated in all aspects of human production and life, summarized as organic and inorganic chemical wastes and radioactive substances generated in industrial production; corrosive and bacteriological wastes generated in the course of medical treatment; and used wastes containing heavy metals generated by people's lives. Drawing on relevant domestic and international regulations and relevant technical information, the main sources of hazardous waste are analyzed in **Table 1** below.

Table 1. Sources of hazardous waste

Source	Industry type	Form of business enterprise	Types of hazardous waste
Industrial sources	Chemical industry	Fine industry	Waste acid, waste paint, waste resin, etc.
	Metal processing	Electroplating, machinery manufacturing, and other enterprises	Waste emulsion, electroplating sludge, waste mineral oil
	Oil industry	Petroleum and chemical industry, oil refining, mining enterprises, pharmaceutical, medicinal materials processing enterprises	Waste oil sludge, oil residue, pot residue, etc.
	Transportation and maintenance	Automobile, ship, train, aircraft, and other maintenance and repair enterprises	Waste oil, waste electrolyte
	Electrical appliances, electronics, and others	Electrical and electronic components enterprises	Waste solvent, waste electrolyte, etc.
	Pharmaceutical manufacturing	Pharmaceutical and herbal processing enterprises	Medical waste, etc.
Social sources	-	-	Waste pesticide, vehicle lead-acid battery, waste lamp tube, waste communication tools, waste paint, and so on
Other	Scientific research and education	Research institutes, colleges, and universities	Waste pesticides, vehicle lead-acid batteries, waste light tubes, waste communication tools, waste paints and other waste reagents, laboratory waste, scrapped research products, etc.

2.2. Feature

With the rapid development of the social economy and the improvement of people's quality of life, the waste left behind by production and life is increasing, and the accumulation of these wastes will produce certain chemical and physical reactions, thus generating toxic substances, posing a threat to the surrounding ecological environment and people's health. These harmful substances are called hazardous waste. The characteristics of hazardous waste determine the degree of environmental risk. Toxicity is one of the most common characteristics of hazardous waste, such as wastes containing heavy metals like mercury, cadmium, lead, etc., which will accumulate in soil and water after entering the environment, and then pass through the food chain, eventually endangering human health. Corrosive wastes, like strong acids and alkalis, can cause serious corrosion and damage to contacted biological tissues, buildings, and equipment, as well as lead to an imbalance in the pH of soil and water bodies [4]. Flammable wastes are easy to burn under certain conditions and may cause fires, which not only pose a direct threat to the safety of the surrounding environment but also generate a large amount of hazardous gases during the combustion process, polluting the atmospheric environment. Reactive wastes, on the other hand, have unstable chemical properties and, when subjected to external stimuli, may undergo violent chemical reactions, such as explosions and the release of toxic gases, causing instant and enormous damage to the surrounding environment and the safety of personnel.

3. Construction of urban environmental risk impact assessment system

3.1. Principles of index system construction

(1) Principle of comprehensive integration: Due to the complexity and variety of hazardous wastes, the factors involved in the environmental risk assessment of centralized hazardous waste disposal enterprises are also multifaceted. Including material hazards, environmental hazards, production factors, management factors, and other factors. It is not possible to simply use a single indicator for evaluation. Therefore, in the process of establishing the evaluation index system of hazardous waste centralized disposal enterprises, we should comprehensively consider all the influencing factors, with high positioning, wide coverage, and strong comprehensiveness, in order to ensure the accuracy of the evaluation results.

(2) Principle of scientificity: The selection of evaluation indicators involves professional knowledge in various fields; therefore, in the process of establishment, experts from various parties should be widely consulted and repeatedly demonstrated and improved, and the process of indicator selection is scientific, reasonable, and recognized by the public.

(3) Principle of dominant factors: The environmental risk evaluation of hazardous waste centralized disposal enterprises has many influencing factors, and the factors are complicated, so the representative and typical dominant factors are selected as the comprehensive evaluation indicators.

(4) Principle of operability: Hazardous waste disposal enterprises have many sources of raw materials and complex types. Evaluation indicators should fully consider the accessibility of data and the degree of difficulty in quantifying the indicators, combining qualitative and quantitative data. It can reflect the connotative characteristics of hazardous waste enterprises and make full use of the existing data and information. While most of the risk evaluation studies are for a single or fixed several substances or corresponding industry enterprises, the hazardous waste centralized disposal enterprises can only consider the main hazardous waste attributes or comprehensive attributes for the time being in order to have a strong operability. Each indicator should be objective and concise, as well as comparable.

(5) Principle of mutual independence: There are many uncertainties in the environmental risk of hazardous waste disposal enterprises, and there are both links and differences between different indicators, which are independent of each other and do not have a mutually inclusive relationship. When constructing the indicator system, the uncertainty of environmental risk should be fully considered, and the status quo and development trend should be

comprehensively considered, so that it has certain universality and is convenient for prediction and control [5].

3.2. Establishment of risk assessment index system for hazardous waste

At present, when establishing the indicator system, the indicators chosen by domestic and foreign countries are mainly related to the following aspects: physical and chemical properties of hazardous substances; environmental persistence; high bioaccumulation; toxicity; detection frequency in environmental monitoring, migration and fate behavior, and environmental background concentration, and so on. In this study, the risk evaluation indicators of enterprises in the chemical and petrochemical industries were referred to, and based on the above principles, domestic experts were widely consulted, and finally the physical and chemical properties, environmental exposure indicators and environmental toxicology indicators were selected, and a risk evaluation system consisting of the target layer, the guideline layer, and the indicator layer was set up in this way (**Figure 1**).

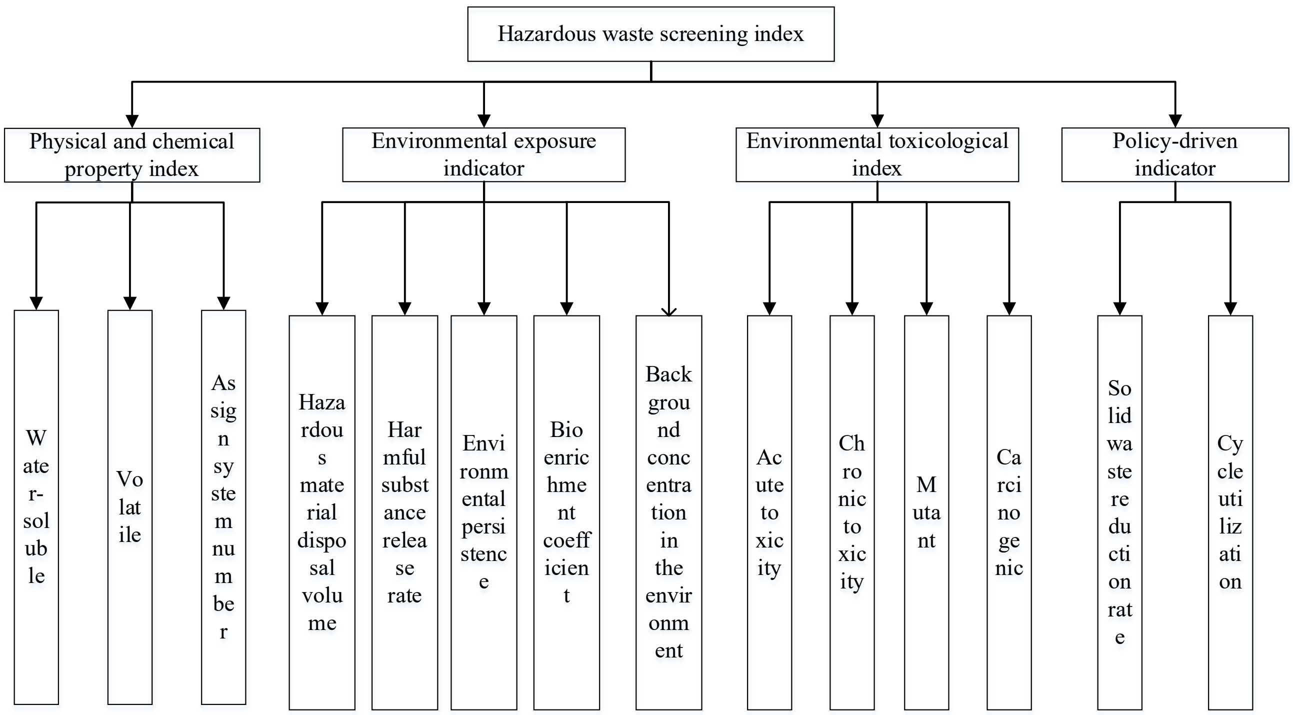

Figure 1. The framework of the established index system

Target level: The risk degree F of a selected harmful substance;

Criterion layer: It is the evaluation factor determined for calculating the risk degree of a certain harmful substance. Here, three evaluation factors are considered, namely: physical and chemical property index B, environmental exposure index B2, and environmental toxicology index B3. Indicator layer: It is the corresponding evaluation factor selected for each evaluation factor of the criterion layer.

3.3. Determination of the weight of evaluation indicators

Nowadays, two commonly used mathematical methods (Telfer's method and hierarchical analysis) are mainly used to determine the weights of indicators. The Telfer method is in the form of a distribution questionnaire that solicits expert opinion or judgement and then calculates the feedback results; the hierarchical analysis method is an effective way of addressing variables that are difficult to quantify for multi-criteria decision-making, and it provides a structured hierarchical thinking model suitable for multi-purpose, multi-criteria, multi-factor problems, with a wide range of applications. In the above indicators, although each indicator is quite important, the focus on different objectives, that these indicators to the centralized disposal of hazardous waste enterprise environmental risk contribution value is not the same, in the specific screening score calculation must also determine the weight of each indicator. Therefore, the Analytic Hierarchy Process (AHP) was used to determine the weights of the indicators. Experts in the hazardous waste disposal industry were invited to score each indicator. The expert advisory team consists of 15 members, including environmental department managers, technical directors from hazardous waste disposal companies, and experts in environmental engineering from research institutes. Among them: Environmental Department Representatives have over 10 years of experience in formulating and implementing solid waste management policies and are familiar with the evaluation criteria for “waste-free cities”; Technical Directors from Enterprises come from typical industries such as chemical, electronic, and medical waste disposal, with experience in frontline technology research and operational management; Experts from Research Institutes specialize in areas like risk assessment of hazardous waste and environmental toxicology, and have led or participated in more than three national-level research projects. The weights of each indicator were calculated based on the experts’ statistical analysis. The relative importance of the indicators was scored using a 5-point Likert scale with the following criteria (**Table 2**).

Table 2. Scoring criteria

Value	Description of importance	Explanation of the meaning
1	It’s not important	The indicators have no substantial impact on risk assessment
2	It’s not that important	The impact of indicators is small and can be ignored
3	Medium importance	The index has a certain influence on risk assessment, but it is not a decisive factor
4	It’s important	Indicators play a key role in risk assessment and need to be considered
5	be of prime importance	The indicators directly determine the risk level and must be included in the evaluation system

Experts scored the relative importance of each pair of indicators in the criterion layer (Layer B) and the index layer (Layer C) through anonymous online questionnaires, and calculated the weight of each index by experts. The basic calculation steps are as follows: First, the calculation of elemental weights; Second, consistency test: the consistency test is performed on the judgment matrix, and the consistency ratio CR is calculated. if CR < 0.1, the consistency of the judgment matrix is acceptable, and the weight of each indicator is calculated by the eigenvector method and other methods. Third, the calculation of the comprehensive weight of each indicator: the calculation formula is:

$$W_{综合} = W_{权重} \times W_{指标}$$

3.4. Risk assessment of hazardous waste

The risk Fj for a selected harmful substance is calculated as follows:

$$F_j = \sum W_i X_j$$

In the formula, Fj represents the comprehensive risk score of the jth evaluation unit (such as a certain plant or region), which is a quantitative embodiment of the hazardous waste risk status of the unit. The higher the score, the higher the risk.

W_i: the comprehensive weight of the ith risk impact index (I = 1,2,n), and represents that $\sum W_i = 1$ indicates the type of index.

X_{ij}: The quantified value of the ith risk influencing factor in the jth evaluation unit. For example, if i represents the toxicity of waste, X_{ij} is the quantified value of the toxicity of hazardous waste in the jth evaluation unit.

4. Case analysis

4.1. City overview

Taking City A as an example, it is an industrial city primarily focused on the chemical and electronics industries, with a high population density. The city's surroundings include important water source protection zones and ecological wetlands. Numerous chemical enterprises within the chemical park generate large amounts of hazardous waste annually, such as waste acids, waste alkalis, and heavy metal-containing sludge; the electronics industry produces electronic waste containing lead, mercury, and other heavy metals. In 2018, the city generated hazardous waste exceeding 1000t in 12 major categories, accounting for 99.3% of the total annual hazardous waste production. Among these, copper-containing waste, surface treatment waste, and incineration residue far exceeded other types of hazardous waste in quantity, making up 78.7% of the total production.

4.2. Environmental management

City A takes standardized management of hazardous wastes as a key to identify and make up for shortcomings through related work, and has achieved remarkable results in the treatment of organic solvents and medical wastes, prevention and control of environmental risks in enterprises, and improvement of the capacity of initial emergency response to environmental emergencies. At the same time, the environmental management of hazardous waste in the industry is constantly standardized through continuous enforcement and inspection actions and special rectification activities to combat environmental violations involving hazardous waste.

4.3. Analysis of results

The indicators were scored in relation to the specific situation in City A, and then a person involved in the environmental management of solid waste in City A was invited to check the results of the scoring of the indicators. The results of the evaluation of the indicators in the environmental risk assessment of hazardous wastes in City A are shown in **Table 3**.

Table 3. Evaluation results of various indicators in environmental risk assessment of hazardous waste in City A

Target level (Level A)	Criteria level (Level B)	A-B layer weight	Indicator layer (C layer)	B-C layer weight	A-C layer weight
Hazardous waste screening index	Physical and chemical property index B1	0.072	Water-soluble C1	0.649	0.047
			Volatile C2	0.279	0.020
			Assign system number C3	0.072	0.005
	Environmental exposure indicator B2	0.279	Hazardous material disposal volume C4	0.077	0.222
			Harmful substance release rate C5	0.435	0.121
			Environmental persistence C6	0.189	0.056
			Bio enrichment coefficient C7	0.189	0.056
			Background concentration in the environment C8	0.077	0.022
	Environmental toxicological index B3	0.649	Acute toxicity C9	0.069	0.045
			Chronic toxicity C10	0.037	0.024
			Mutant C11	0.298	0.193
			Carcinogenic C12	0.298	0.193
	Policy-driven indicator B4	0.349	Solid waste reduction rate C13	0.290	0.056
			Cycle utilization C14	0.276	0.049

The consistency test of each judgment matrix is as follows:

Criterion level (Layer B) judgment matrix: the maximum eigenvalue λmax = 4.123, the consistency index $CI = \frac{\lambda_{max} - n}{n-1}$ = 0.041, the random consistency index RI = 0.90 (when n = 4), the consistency ratio CR = CI/RI = 0.046 < 0.1, passing the consistency test.

Criterion layer (C layer) judgment matrix: Taking environmental exposure index B_2 as an example, the maximum eigenvalue of its criterion layer judgment matrix is λmax = 4.123 = 5.218, CI = 0.0545, RI = 1.12 (n = 5), CR = 0.0545/1.12 = 0.0487 < 0.1, and the consistency is acceptable.

The results of risk evaluation are shown in **Table 4**.

Table 4. Environmental risk assessment results of hazardous waste in City A

Indicator layer	Level of risk
Water-soluble	2
Volatile	3
Assign system number	1
Hazardous material disposal volume	2
Harmful substance release rate	3
Environmental persistence	2
Bio enrichment coefficient	2
Background concentration in the environment	2
Acute toxicity	3
Chronic toxicity	2
Mutant	1
Carcinogenic	2
Solid waste reduction rate	1
Cycle utilization	2
Overall score	2.234
Order of evaluation	Greater risk

5. Conclusion

The risk assessment of hazardous waste under the concept of “waste-free city” is the core link to integrate the sustainable development and ecological safety of the city, so it is necessary to clarify the role of centralized treatment of hazardous waste, and combine it with its own hazardous waste emission status, construct evaluation indexes, and choose the appropriate method to realize the effective treatment of hazardous waste.

This study constructs a method for environmental risk assessment of urban hazardous waste. The method, for the first time, takes the city as a whole, and evaluates the environmental risk of hazardous waste in City A from three aspects, including physical and chemical properties, environmental exposure, and environmental toxicology, using hierarchical analysis. The results show that City A has a “greater risk” because of the concentration of the chemical and electronic industries, the higher amount of hazardous wastes disposed of, and the release rate. The results show that the overall risk level of City A is “higher risk” due to the concentration of chemical and electronic industries and the high volume and release rate of hazardous waste disposal, in which the risk level of volatile substances, release rate of hazardous substances, acute toxicity and other indicators reaches level 3 (higher risk), which highlights the environmental hazards caused by the imbalance between the industrial structure and disposal capacity. Therefore, in the process of building a "waste-free city," City A should actively adopt information-based supervision to construct a smart management system covering the entire lifecycle. For example, it can use a technology integration solution combining blockchain, IoT, and big data to build a digital supervision system that spans the entire chain of hazardous waste from "generation-collection-transportation-disposal-resource utilization." Implement regional joint prevention and control: innovate cross-administrative collaborative mechanisms, referring to the "Yangtze River Economic Belt Solid Waste Joint Prevention and Control Implementation Plan," it is recommended to establish a "regional hazardous waste emergency disposal resource pool" and other corresponding measures for optimization and adjustment, to improve the efficiency of hazardous waste treatment, thereby minimizing its impact on China's environment and creating a comfortable and healthy living environment for the public.

This study is limited in not considering the impact of illegal hazardous waste transfer, regulatory blind spots for small and micro enterprises, and dynamic social factors on risk prevention. Future research could focus on developing an LCA-based coupled assessment model for environmental risks and economic costs of hazardous waste, exploring intelligent monitoring technologies for illegal transfer risks, innovating regulatory models for hazardous waste in small and micro enterprises, and constructing a socio-technical co-evolution model to improve the evaluation system and control strategies.

Disclosure statement

The author declares no conflict of interest.

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