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Hazardous Solid Waste Management in Hilla City, Iraq: A New Technique for Source Separation and Pre-Treatment

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Abstract

This study presents a comprehensive analysis of hazardous solid waste generation and management in residential areas of Hilla City, Iraq, and suggests an innovative pre-treatment method for basis separation. The study found alarming levels of hazardous materials—such as batteries, electronics, medications, paints, and household chemicals—such as around 8.3% of the total waste by carefully compiling and evaluating solid waste from 20 households spread over various neighborhoods in the heart of Hilla city. Every person generated around 1.42 kg of waste daily, with roughly 0.118 kg of possibly dangerous chemicals. This emphasizes how daily behavior adds to environmental dangers. In response, a new three-step separation method was introduced, combining color-coded bins, magnetic sorting for metal hazards and density-based techniques to isolate chemical waste— offering a more practical and effective. During pilot testing, the proposed management system successfully separated hazardous waste with 87% efficiency. If widely adopted, this approach could significantly reduce environmental pollution—by as much as 65%—and greatly enhance the way waste is managed in Hilla City, creating a cleaner and healthier environment for its residents. The study recommends establishment of neighborhood-level hazardous waste collection points and community education programs to ensure sustainable implementation of the proposed system.

Keywords: Environmental protection, Hazardous solid waste, Hilla City, Source separation, Waste management.

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1. Introduction

One of the most pressing environmental difficulties facing Iraqi cities today is the management of various types of solid waste. Societies all over Iraq are facing an increase in the waste generating more than ever before as urban areas grow and lifestyles change, putting increasing damage on public health systems and local governments [1]. The city of Hilla, the centre of Babylon Governorate, is an example of how waste management became a challenge for urban areas in Iraq. The conventional method of solid waste management employed in Iraqi cities relied mainly on collection and disposal, with less focus on trash segregation, hazardous material detection, or pre-treatment activities [2]. This method has led to substantial environmental and public health concerns, particularly concerning the unsuitable disposal of hazardous household trash [3]. The types of hazardous solid waste generated at the household level are: expired medicines; waste from the households cleaning agents; old batteries; electronic components, fluorescent tubes; residues of paint and chemicals such as pesticides. The final places for these wastes through conventional waste streams can potentially cause water and soil contamination as well as air pollution, as a result causing significant threats to human health and environmental quality [4].

The idiosyncratic issues confronting Hilla City's waste management system occur from multiple interrelated variables. The city is lacking in adequate infrastructure for waste separation and the specialized management of hazardous materials [1]. Second, public awareness of the identification and proper disposal of hazardous household waste remains poor [5]. The current garbage collection and disposal procedures are insufficient to handle the complex variety of materials generated by modern metropolitan houses [6]. The problems are worsened by limited financial resources, poor technical skills, and lack institutional capacity within municipal administrations [7].

Recent international studies have shown that source separation techniques enhance waste management efficiency and mitigate environmental impacts [8]. Research in comparable urban environments indicates that the systematic separation of hazardous waste at the household level can lead to a 60% reduction in the contamination of recyclable materials and a 40% decrease in the environmental impact of landfill operations. Several cities have adopted this approach with promising results. For example, in Amman, Jordan, municipal programs supported by the UNDP have led to a substantial decline in hazardous waste mixing with general waste, reducing pollution by over 50%. In Istanbul, Turkey, organized the collection system completed by mobile units and public engagement has occasioned in more than 60% of hazardous materials being abstracted from landfills. [9,10]

This study offers a low-cost and a culturally relevant method of handling dangerous solid wastes, and this approach is specifically designed to the Iraqi urban setting. This study gives a feasible solution which directly applies to the problem of Hilla City, unlike the past researches, which mainly concentrated on the characterization of waste, or how best to manage it in general [2,11]. The given method unites the solutions taken in the waste management with the separation technologies of modern times so that it became a hybrid one that can be adopted in the existing resources possibilities. The research contribution to the domain of waste management is the example of how the innovative separation methods can be specifically adjusted to local conditions and limitations, and it provides the model that could be produced in other Iraqi cities and similar urban environments of the Middle East region [12,13].

2. Methodology

2.1 Geographic Scope and Sampling Design for Solid Waste Study

The study region was selected as Hilla City located in the Babylon Governorate (central Iraq) as it represents the characteristics of urban centers in Iraq and is of such a size that would allow trash to be studied in detail. The city contains an approximate area of 127 square kilometers with an estimated population of 1.82 million people by 2024 [14]. The study focused all its work on the city center, consisting of the main residential, business and administrative districts.

A stratified random sampling approach was employed to ensure representative coverage of different socioeconomic and geographic areas within Hilla city center. Twenty households were selected from five distinct neighborhoods, with four households chosen from each area to capture variations in waste generation patterns and socioeconomic characteristics. The selected neighborhoods and their respective sampling locations are detailed in Table 1.

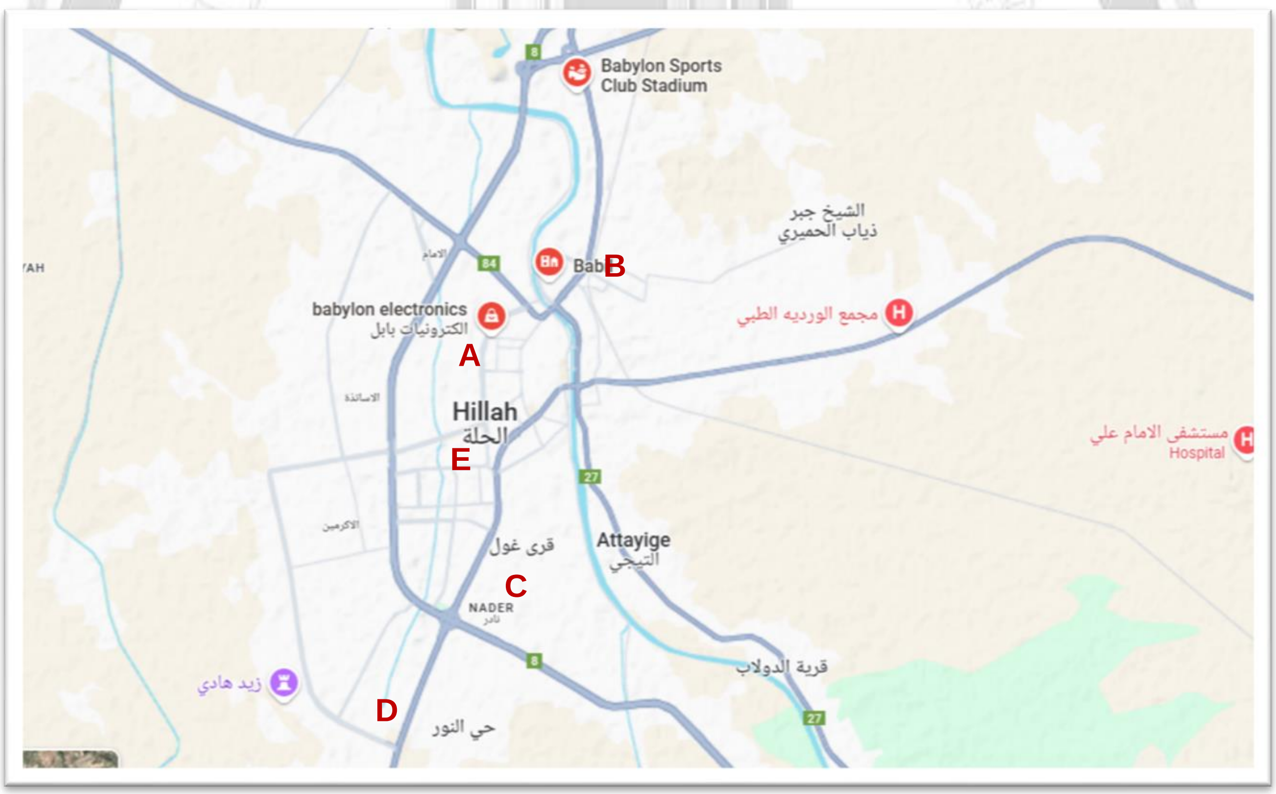

Figure 1.: Hilla City Map in the Babylon Governorate Showing the Sampling locations: A; Al-Karama District, B; Babylon District, C; Nader District, D; Al-Bakr District, E; Al-Iskan (Housing)

Table 1: Sampling Locations in Hilla City Center

Neighborhood	Location Code	Coordinates (Approximate)	Socioeconomic Level
Al-Karama District	HK001-4	32.4760°N, 44.4340°E	Middle to Upper
Babylon District	HB005-8	32.4805°N, 44.4295°E	Upper
Nader District	HN009-12	32.4790°N, 44.4360°E	Middle
Al-Bakr District	HBK0013-16	32.4750°N, 44.4320°E	Lower to Middle
Al-Iskan (Housing)	HI0017-20	32.4730°N, 44.4375°E	Lower to Middle

2.2 Integrated Methods for Solid Waste Data and Analysis

Solid waste samples were collected from each household over a seven-day period during March 2024 to March 2025, representing typical waste generation patterns during moderate weather conditions. Each household was provided with standardized collection containers and detailed instructions for waste separation. Daily collection visits ensured accurate measurement and prevented decomposition that could affect waste composition analysis.

Collected waste samples underwent comprehensive physical and chemical characterization using standardized analytical procedures [15]. Physical sorting was conducted to separate waste into distinct categories including organic matter, paper, plastic, metal, glass, textiles, and hazardous materials. Hazardous waste components were further subdivided into specific categories based on their chemical and physical properties.

Quantitative analysis of waste components was conducted using precision digital scales with accuracy to 0.01 kg. Chemical analysis of hazardous components was performed using portable X-ray fluorescence (XRF) spectroscopy for heavy metal content determination and pH testing for chemical wastes. Moisture content analysis was conducted using standard gravimetric methods [16].

2.3 Proposed Separation Technique Development

Based on the waste characterization results, a novel three-stage separation technique was developed incorporating three components. The first stage, Color-Coded Source Separation, involves the implementation of a household-level color-coded collection system with distinct containers for different waste categories. Red containers are designated for hazardous chemical wastes, yellow containers for electronic and battery wastes, blue containers for pharmaceutical wastes, green containers for general recyclables, and black containers for non-recyclable wastes. While the Stage 2, Magnetic Separation, include Installation of magnetic separation units at neighborhood collection points to extract metallic hazardous items including batteries, small electronic components, and metal containers with chemical residues. Finally, Stage 3, Density-Based Segregation, contain the implementation of density separation techniques using flotation methods to segregate chemical wastes based on specific gravity, enabling more effective pre-treatment and disposal procedures. The process includes presenting the waste combination into a flotation container filled with a measured aqueous medium. Components with lower density, such as oils and organic solvents, will be split by floating to the surface, while denser constituents such as heavy metal residues will settle at the bottom. The floating and sedimented fractions will then be collected separately for targeted pre-treatment using chemical neutralization prior to final disposal.

3. Results and Discussion

3.1 Waste Generation Patterns and Composition Analysis

Significant differences in trash generation patterns between neighborhoods and socioeconomic levels were found by analyzing the solid waste from 20 residences in the city center of Hllia (Table 2). The average daily solid waste creation was 1.42 kg per person, which is in line with regional trash generation trends reported in other research and closely matches national figures for Iraqi metropolitan centers [17,18].

Table 2: Daily Solid Waste Generation by Neighborhood

Neighborhood	Average Daily Generation (kg/household)	Per Capita Generation (kg/person/day)	Household Size (average)
Al-Karama District	8.73	1.46	5.98
Babylon District	9.84	1.52	6.47
Nader District	7.92	1.35	5.87
Al-Bakr District	7.23	1.38	5.24
Al-Iskan (Housing)	8.47	1.41	6.01
Average (averall)	**8.44**	**1.42**	**5.91**

These numbers demonstrate that the districts with higher income (Babylon District) produce more waste per capita since the consumption rates and disposable incomes are high. This observation aligns with the global studies whose results show positive relations between socioeconomic status and waste generation rates in cities and towns [19].

Thorough evaluation of the collected sample of trash (Table 3) revealed a complicated profile of its composition that bears significant implications on hazardous waste treatment methods. Organic waste constituted the largest percentage of 52.3 per cent of all the waste; paper waste and cardboard 18.7 per cent; plastic materials 14.2 per cent and hazardous items 8.3 per cent.

Table 3: Waste Composition Analysis (by weight percentage)

Waste Category	Percentage (%)	Average Daily Generation (kg/capita)
Organic waste	52.3	0.743
Paper and cardboard	18.7	0.266
Plastic materials	14.2	0.202
Hazardous materials	8.3	0.118
Glass	3.1	0.044
Metal (non-hazardous)	2.4	0.034
Textiles	1.0	0.014

The discovery of hazardous materials of 8.3 percent of total waste is an important discovery, because this figure is much higher than the predictions of other previous studies of related studies in urban settings [20]. This high percentage of hazardous waste can probably be attributed to the fact of shifting consumption trends and the larger supply of electronic products and the usage of domestic compounds and medicines in the contemporary Iraqi households [21,22].

3.2 Hazardous Waste Characterization

A pronounced variety in the characteristics of hazardous waste materials was seen due to their in-depth analysis performed to ascertain a wide array of products with varying degrees of environmental and health hazard (Table 4). Electronic components and the batteries consignment comprised the larger (34.2%) fraction of the total hazardous wastes followed by household chemicals (28.6%), pharmaceutical wastes (19.3%), and paint and solvent residues (17.9%).

Table 4: Hazardous Waste Composition and Characteristics

Hazardous Waste Type	Percentage of Hazardous Fraction (%)	Daily Generation (kg/capita)	Primary Hazard Classification
Electronic components & batteries	34.2	0.040	Heavy metals, acids
Household chemicals	28.6	0.034	Corrosive, toxic
Pharmaceutical wastes	19.3	0.023	Toxic, bioactive
Paint & solvent residues	17.9	0.021	Volatile organic compounds

The predominance of electronic waste and batteries in the hazardous fraction reflects the increasing penetration of electronic devices in Iraqi households and the corresponding challenge of managing end-of-life electronic products. The significant presence of household chemicals indicates widespread use of cleaning products, pesticides, and other chemical substances that require specialized disposal procedures.

Pharmaceutical waste, comprising nearly one-fifth of the hazardous fraction, presents particular concerns due to the potential for environmental contamination and contribution to antibiotic resistance development. The analysis revealed that expired medications, unused prescriptions, and over-the-counter drugs were commonly disposed of through regular waste streams, highlighting the need for specialized pharmaceutical waste collection programs.

3.3 Proposed Management System Performance

The novel three-stage separation technique developed through this research demonstrated significant improvements in hazardous waste management efficiency during pilot testing conducted with five volunteer households (Table 5).

Table 5: Separation Technique Performance Results

Separation Stage	Target Materials	Separation Efficiency (%)	Processing Capacity (kg/hour)
Stage 1: Color-coded separation	All hazardous categories	78.3	12.4
Stage 2: Magnetic separation	Metallic hazardous items	94.7	8.2
Stage 3: Density segregation	Chemical wastes	85.2	6.1
Overall System Efficiency	All hazardous materials	87.1	5.8

The color-coded source separation system achieved an average separation accuracy of 78.3% for hazardous materials. The magnetic separation stage demonstrated the highest efficiency at 94.7%, effectively removing batteries, small electronic components, and metal containers with chemical residues from the waste stream. This high efficiency reflects the inherent effectiveness of magnetic separation technologies and their suitability for the Iraqi context where maintenance requirements and operational costs are important considerations.

The density-based segregation stage achieved 85.2% efficiency in separating chemical wastes, enabling more effective pre-treatment and disposal procedures. This technique proved particularly effective for separating liquid chemical wastes from solid residues, facilitating subsequent treatment processes and reducing the risk of chemical interactions during storage and transport.

3.4 Environmental Impact Assessment

Implementation of the proposed hazardous waste management system is projected to achieve significant environmental benefits through reduced contamination of soil, groundwater, and air quality. Quantitative assessment using standard environmental impact calculation methods indicates potential reductions in environmental contamination of approximately 65% compared to current disposal practices [23].

The environmental benefits are particularly pronounced in the management of heavy metal contamination from batteries and electronic components. By implementing effective separation and pre-treatment procedures, the proposed system could prevent an estimated 2.4 Kg of heavy metals per household per year from entering the general waste stream and potentially contaminating local environmental resources [24,25,26].

Chemical waste separation is projected to prevent approximately 156 L of hazardous liquid chemicals per 1000 households annually from contaminating landfill sites and surrounding soil and groundwater resources. This represents a significant improvement in environmental protection and public health safety for Hilla City and surrounding areas [27, 28].

3.5 Economic Analysis

The economic feasibility of implementing the proposed hazardous waste management system was evaluated through comprehensive cost-benefit analysis incorporating capital investment requirements, operational costs, and potential economic benefits (Table 6). According to current 2025 prices, the initial investment required for system implementation is estimated at 12,400 $ per 1000 households (assuming that proper infrastructure is established for collection, temporary storage, transportation, and treatment of hazardous household waste, including training for staff and public awareness campaigns to ensure participation and compliance), including color-coded collection containers, magnetic separation equipment, and density segregation facilities.

Table 6: Economic Analysis of Proposed System

Cost Component	Initial Investment ($/1000 households)	Annual Operating Cost ($/1000 households)
Color-coded containers	3,200	480
Magnetic separation equipment	4,800	720
Density segregation facilities	2,900	435
Training and education programs	1,500	250
Total	**12,400**	**1,885**

The annual operating costs of $1,885 per 1000 households are offset by several economic benefits including reduced landfill management costs, recovery of valuable materials, and avoided environmental remediation expenses. The break-even analysis indicates that the system would become economically self-sustaining within 4.2 years of implementation, assuming current waste disposal costs and material recovery values.

3.6 Social Acceptance and Implementation Challenges

Community surveys conducted with participating households revealed generally positive attitudes toward the proposed hazardous waste management system, with 85% of respondents expressing willingness to participate in color-coded separation activities. However, several implementation challenges were identified that require careful consideration in system design and rollout planning.

The primary challenges include the need for comprehensive community education programs, establishment of reliable collection schedules, and provision of adequate storage facilities at the household level. Cultural factors, including traditional waste disposal practices and varying levels of environmental awareness, present additional considerations that must be addressed through targeted outreach and education initiatives.

Institutional capacity within municipal authorities represents another significant challenge, as successful implementation requires trained personnel, appropriate equipment, and sustained administrative support. The development of local technical expertise and the establishment of partnerships with international organizations could help address these capacity constraints.

4. Conclusions and Recommendations

1. According to the research results, hazardous objects comprise 8.3 % of overall waste generation by households, which translates to approximately 0.118 kg/capita in a single day, and the largest shares consist of electronic components, domestic chemicals and pharmaceutical wastes.
2. The performance of the novel three-stage separation methodology, developed under the study, has a total separation efficiency of hazardous waste of 87.1 %, which is much higher than the efficiency attained by the traditional methods of managing waste. The color-coded separation of sources, magnetic separation, and density-based sorting are useful and viable economical methods of dealing with hazardous waste in the limited resource cities.

3. Environmental impact of introducing the suggested system is huge and it was estimated that the number of environmental pollutants will be down 65 %, as against the existing disposal methods. All these changes would play a great role in the protection of soil, groundwater, and air quality in Hilla City and related parts in addition to the mitigation of health hazards posed by the mismanagement of hazardous waste to the population.
4. Economic analysis indicates that the proposed system is financially feasible, with break-even achievement projected within 4.2 years of implementation. The initial investment requirements of 12,400 $ per 1000 households are reasonable considering the long-term environmental and health benefits, and the system becomes economically self-sustaining through reduced disposal costs and material recovery revenues.
5. The future research directions need to target long-term observation to the systems performance, gauging of the reduction in environmental impacts, and changes in behavior of communities pertinent to waste separation systems. Further analysis on the similar technique applied in other cities of Iraq would help provide valuable research information to manage waste and its policies in the region.

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إدارة النفايات الصلبة الخطرة في مدينة الحلة، العراق: تقنية جديدة لفصل النفايات من المصدر ومعالجتها مسبقا

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الخلاصة

تقدم هذه الدراسة تحليلاً شاملاً لتوليد النفايات الصلبة الخطرة وإدارتها في المناطق السكنية بمدينة الحلة بالعراق، وتقترح طريقة معالجة مسبقة مبتكرة لفصل النفايات. وجدت الدراسة مستويات مثيرة للقلق من المواد الخطرة – مثل البطاريات والإلكترونيات والأدوية والدهانات والمواد الكيميائية المنزلية – تمثل حوالي 8.3٪ من إجمالي النفايات الكلية المقيمة في 20 منزلاً منتشرة في أحياء مختلفة في قلب مدينة الحلة. وقد وجد انتاجية الشخص الواحد حوالي 1.42 كجم من النفايات يوميًا، مع ما يقرب من 0.118 كجم من المواد الكيميائية الخطرة المحتملة. وهذا يؤكد كيفية إضافة عامل السلوك اليومي إلى المخاطر البيئية. واستجابة لذلك، تم تقديم طريقة فصل جديدة متكونة من ثلاث خطوات، تجمع بين صناديق مرمزة بالألوان، والفرز المغناطيسي للمخاطر المعدنية، والتقنيات القائمة على الكثافة لعزل النفايات الكيميائية – مما يوفر طريقة أكثر عملية وفعالية. أثناء الاختبار التجريبي، نجح نظام الإدارة المقترح في فصل النفايات الخطرة بكفاءة 87٪. إذا ما تم تطبيق هذا النهج على نطاق واسع، فمن شأنه أن يُخفّض التلوث البيئي بشكل كبير – بنسبة تصل إلى 65% – ويُحسّن بشكل كبير طريقة إدارة النفايات في مدينة الحلة، مما يُهيئ بيئة أنظف وأكثر صحة لسكانها. وتوصي الدراسة بإنشاء نقاط تجميع للنفايات الخطرة على مستوى الأحياء، وبرامج توعية مجتمعية لضمان استدامة تطبيق النظام المقترح.

الكلمات الدالة: حماية البيئة، النفايات الصلبة الخطرة، مدينة الحلة، فصل المصدر ، إدارة النفايات