The Role of Artificial Intelligence in Waste Management Crowds During the Arbaeen Pilgrimage in Karbala: Towards Smart and Sustainable Solutions

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Abstract

The Arbaeen pilgrimage in Karbala is one of the largest religious gatherings in the world, generating complex environmental challenges—most notably in urban waste management due to extreme crowd density and limited infrastructure.

The problem addressed in this study lies in the inadequate adoption of artificial intelligence (AI) technologies in managing crowd-generated waste during the pilgrimage, which hampers the realization of a sustainable urban system responsive to mass events.

The research hypothesizes that the integration of AI tools can significantly enhance the efficiency, responsiveness, and environmental sustainability of waste management systems during mass religious occasions. The significance of this study stems from its contribution to proposing an AI-based smart waste management framework, tailored to the specific context of Karbala, and capable of addressing the challenges of both scale and religious spatial sensitivity.

To achieve this, the study employed a mixed-methods approach combining analytical review, comparative case analysis, and a field survey conducted in eight neighborhoods within the historical center of Karbala during the 1445 AH Arbaeen season. Data were collected through structured observations, municipal records, and semi-structured interviews with local service providers. Temporal and spatial boundaries: Data were collected from field observations, municipal records, and interviews with local service personnel. The sample included municipal employees, representatives of the shrines, and workers in the Husseini service processions within the historic center of Karbala. The time period extended from Muharram to the end of Safar 1445 AH, with a special focus on the peak days of the Arbaeen pilgrimage.

The research proposes technical solutions including smart sorting robots, sensor-enabled waste bins, drone monitoring, and predictive analytics platforms. Results revealed weak digital infrastructure, lack of coordinated governance, and minimal AI integration in existing practices.

The study recommends a national strategy for AI-based waste management, establishing real-time monitoring centers, community awareness campaigns, and encouraging applied research in environmental AI. These steps would transform current waste challenges into opportunities for smart, sustainable urban management.

Keywords: Artificial intelligence, waste management crowds, Arbaeen pilgrimage, smart solutions, environmental sustainability, smart cities, infrastructure Smart robots, digital transformation in urban services,

Introduction

Solid waste management in religious-touristic cities like Karbala becomes highly challenging during mass events such as the Arbaeen pilgrimage due to extreme crowd density and limited infrastructure. The growing number of visitors intensifies pressure on urban services, demanding smart and rapid solutions. Artificial intelligence (AI) offers effective tools to analyze urban data, predict waste patterns, and optimize operations through machine learning and IoT-based systems. These technologies enable smarter waste collection, better resource allocation, and improved municipal planning. This research explores the potential of AI in enhancing waste management during Arbaeen, employing a clear methodology with defined objectives, a representative sample, and spatial-temporal boundaries. A field study in eight neighborhoods during the 1445 AH Arbaeen season revealed limited digital infrastructure and AI use. The study proposes practical AI-based solutions and calls for a national strategy to transform waste challenges into opportunities for sustainable urban development.

The Concept of the Role of Artificial Intelligence

Artificial intelligence (AI) refers to the ability of computer systems to simulate aspects of human cognition—such as learning, reasoning, and decision-making—through algorithms that process vast and dynamic data streams (Peña, 2018). In the context of urban challenges, AI extends beyond automation, becoming a strategic tool for analyzing complex systems and supporting timely, evidence-based decisions. Within the specific framework of the Arbaeen pilgrimage, where millions of visitors converge in a short period, AI plays a crucial role in addressing the operational complexity of waste management. This includes real-time monitoring of waste accumulation, predicting spatial and temporal patterns of crowd movement, and optimizing resource allocation. Here, waste is not only a logistical burden but a dynamic indicator of human activity, requiring intelligent systems to ensure efficiency and environmental sustainability.

Thus, the role of AI in this context is not theoretical but applied and targeted—it is a means to enhance the responsiveness of urban services while respecting the cultural and religious sensitivity of the event.

Criteria for the Use of Artificial Intelligence in Waste Management

Integrating artificial intelligence into waste management is not merely a technical transformation; it represents a structural transformation that requires a rigorous normative framework that ensures operational efficiency, environmental sustainability, and social justice. These criteria intersect with the actual challenges posed by urban systems, particularly in contexts with seasonal population density, such as the Arbaeen pilgrimage in Karbala. The most prominent of these criteria are listed below (Aydın, 2023, p. 432):

A. First – Interoperability:The effectiveness of smart systems requires their technical integration with Internet of Things (IoT) networks, low-power communication networks (such as LoRa), and municipal and service entity databases. This integration is a prerequisite for ensuring immediate and comprehensive responses to waste generation, transportation, and treatment operations.

B. Second – Scalability:Sudden changes in waste quantities, such as in religious crowds, require smart systems to be flexible and scalable in terms of computing processing and data storage capabilities, without causing performance degradation or delayed response.

C. Third – Environmental and Economic Efficiency:AI systems must achieve a delicate balance between operational costs and environmental and social returns. This efficiency includes reducing carbon emissions, improving recycling rates, and reducing collection and transportation costs, thus enhancing the added value of the system without placing excessive burdens on operators.

D. Fourth – Cybersecurity:Data and information protection is the cornerstone of the reliability of intelligent systems, especially in environments that rely on wireless sensing and open digital infrastructure. Any potential breach poses a direct threat to the system's efficiency and could lead to disruptions in waste management or the exposure of sensitive data related to crowd distribution or congestion locations.

E. Fifth – Good Governance of AI Applications:True sustainability of AI use cannot be achieved without a robust governance framework that defines responsibilities, guides policies, and monitors impact. Governance encompasses institutional, technical, and societal aspects, ensuring integration among stakeholders, promoting fair use, transparency in evaluation, and compliance with ethical and environmental principles. Adherence to these seven criteria is a prerequisite for the rational and effective use of AI in waste management, especially in complex and sensitive environments such as the Arbaeen Pilgrimage, where technical needs intersect with humanitarian and cultural considerations.

Types of Waste in Urban Crowds: A Classification Framework to Support Smart Systems:

In urban crowd contexts such as the Arbaeen pilgrimage, waste generated varies in terms of source and composition, requiring careful classification to help develop smart management solutions. The most prominent types are:Table 1.

Table 1: Classifications and Types of Waste According to Multiple Sources

No.	Waste Category	Examples	Notes
1	Municipal Solid Waste (MSW)	Food waste, paper, cardboard, plastic, glass, metals, textiles	Most common during mass religious events
2	Organic Waste	Food scraps, vegetable waste, untreated paper	Can be composted or converted into biogas
3	Inorganic Waste	Plastic, glass, metals, ceramics	Often recyclable
4	Hazardous Waste	Batteries, cleaning chemicals, expired medicines, electronic waste	Needs special handling and safe storage
5	Medical Waste	Used gauze, gloves, medical tools, contaminated items	Found in emergency and temporary health service areas
6	Construction & Demolition	Concrete, bricks, wood, metals	Results from temporary infrastructure installations
7	Light Industrial Waste	Printing remains, packaging, temporary event equipment	Generated by logistical and support activities during mass gatherings
Source: Prepared by the researcher based on various sources			

lobal and Arab Experiences in Using Artificial Intelligence for Waste Management

The use of artificial intelligence in waste management represents one of the most prominent aspects of digital transformation in contemporary urban systems. The effectiveness of this approach has been demonstrated through a number of pioneering international and Arab experiences, whose design and implementation were based on standards of accuracy, integration, scalability, environmental efficiency, governance, and cybersecurity.

A. **Global Experiences**

1. **South Korea - Ecube Labs :**

Developed smart waste compactor containers based on sensors connected to AI-powered control platforms. This resulted in:

- Reducing the number of waste collection trips by up to 80%.
- Increasing the container capacity by up to 700%.
- Significantly reducing operational emissions.

2. **Johannesburg, South Africa**

The municipality implemented a pilot project to apply artificial intelligence to sort and track waste in low-income neighborhoods using sensors linked to an interactive application to analyze time patterns. This contributed to:

- Improving the temporal allocation of resources.
- Improving the responsiveness of field crews.

3. **European Countries - CNN Applications in Waste Sorting**

As part of smart environmental initiatives, several cities have used convolutional neural network (CNN) algorithms to visually classify waste, achieving accuracy rates of over 95%, while significantly reducing carbon emissions resulting from transportation and manual sorting.

B. Second: Arab Experiences

1. **Mecca - Smart TUHR System**

The Holy Capital Municipality developed a system based on Internet of Things (IoT) and artificial intelligence technologies to monitor container fullness and send immediate alerts to the relevant authorities. The system resulted in:

- Reducing fuel consumption and operating costs.
- Improving response time during the Hajj and Umrah seasons.

2. **Sharjah - Bee'ah Authority**

Sharjah implemented a smart waste city project, using advanced artificial intelligence models, including deep learning algorithms and predictive analysis, with the aim of:

- Improving the efficiency of spatial distribution of vehicles.
- Reducing non-recyclable waste.
- Ensuring transparency and security in handling environmental data.

3. **Saudi Arabia - National Waste Strategy**

The Ministry of Environment, Water, and Agriculture launched a national framework based on artificial intelligence to improve tracking systems, analyze environmental data, and develop unified databases across agencies, enhancing:

- Institutional integration
- Data-driven planning in municipal waste management.

Criteria Analysis of Presented Global and Arab Experiences in Using Artificial Intelligence for Waste Management

These experiences indicate that the application of artificial intelligence in waste management can only succeed if the following criteria are met:

- Accurate performance and stability of algorithms.
- Integration of smart systems with digital infrastructure.
- Scalability and adaptability to sudden changes in waste volume.
- The availability of a governance framework that ensures fairness, accountability, and data protection.

These criteria are doubly important in crowded contexts, such as the

Arbaeen pilgrimage in Karbala, where waste poses a complex environmental and administrative challenge that requires smart and sustainable solutions. Table 2

Table 2 Criteria Analysis of Presented Global and Arab Experiences in Using Artificial Intelligence for Waste Management

Country / Project	Infrastructure Integration	Scalability	Environmental & Economic Efficiency	Cybersecurity	Good Governance
South Korea – Ecube Labs	√	√	√	X	X
Johannesburg – South Africa	√	X	√	X	X
Europe – CNN Applications	√	√	√	X	X
Mecca – TUHR Smart System	√	√	√	X	√
Sharjah – Bee'ah	√	√	√	√	√
Saudi Arabia – National Strategy	√	√	√	√	√

Source: Prepared by researchers based on literature review and previous studies.

Notes:

√ = Clearly available or explicitly mentioned in the application.

X = Not mentioned or no evidence of implementation in the available sources.

Sustainability and Smart Waste Management

Sustainability forms a fundamental framework for achieving effective and lasting waste management during large-scale events such as the Arbaeen pilgrimage in Karbala. Artificial intelligence technologies can play a pivotal role in enhancing this framework by improving the collection and sorting of waste and reducing the negative environmental impact caused by pollution and waste accumulation.

From an economic perspective, smart solutions allow for improved operational efficiency and reduced costs associated with waste management, in addition to promoting recycling and turning waste into economic resources. Socially, AI contributes to providing a clean and healthy environment for visitors and local residents (Al-Ameedee & Al-Baghdadi, 2025, p.311), while also raising awareness and encouraging community participation—supporting the creation of a more environmentally responsible society.

Thus, integrating AI with sustainability principles becomes an essential element in achieving smart and sustainable urban solutions that match the challenges of waste management in such major events.

A. Environmental Dimension:

AI contributes to reducing waste accumulation and pollution by improving collection and sorting processes, preserving air and water quality, and supporting the protection of natural resources, through:

- Reducing waste accumulation and pollution in public areas (Al-Ameedee, 2023, p.21).
- Enhancing air and water quality by minimizing emissions from waste collection and transport.
- Supporting recycling processes and the conservation of natural resources.

B. • Economic Dimension:

Smart systems improve the efficiency of waste management, reducing operational costs and enhancing economic opportunities through recycling and treating waste as a sustainable resource, by:

- Lowering operational costs through intelligent and efficient waste collection scheduling.
- Promoting waste utilization as an economic resource through sorting and recycling.
- Supporting the local economy by improving waste management efficiency.

C. • Social Dimension:

Smart waste management provides a clean and healthy environment for visitors and residents, fosters community engagement and environmental awareness, and strengthens the sense of shared responsibility for maintaining the city, through:

- Providing a clean and healthy environment for visitors and local residents.
- Reducing health risks associated with waste accumulation (Al-Ameedee, 2023, p.23).
- Enhancing awareness and community participation in maintaining city cleanliness.
- Strengthening social bonds and the sense of shared responsibility.

Urban and Religious Characteristics of the City of Karbala: Framework for Understanding Crowd and Waste Management Challenges

The holy city of Karbala is one of the most prominent religious cities in the Islamic world and holds a special spiritual status due to the presence of the shrine of Imam Hussain (peace be upon him). Each year, particularly during the Arbaeen pilgrimage, the city transforms into a massive religious hub, attracting millions of visitors from various nationalities in one of the largest peaceful human gatherings worldwide (Al-Ameedee & Al-Baghdadi, 2024, p.408).

From an urban perspective, Karbala is characterized by a built environment that combines a dense traditional fabric around the holy shrines with modern urban extensions surrounding it. This reality presents increasing challenges to the infrastructure's ability to cope with the massive seasonal pressure, especially in terms of waste management, as waste generation surges sharply during the pilgrimage days.

Accordingly, Karbala represents a sensitive urban model that requires smart and sustainable solutions in managing its essential services—particularly as the technical and demographic dimensions of the pilgrimage expand—making the integration of artificial intelligence into crowd waste management a pressing necessity rather than a luxury.

The city of Karbala is an ancient and renowned Islamic city with a history as old as the civilizations of Iraq. Its name appeared in cuneiform inscriptions dating back to the first millennium BCE, under the name *Karbalata*, where the root of the word is *Karbli*, and the suffix *-ta* is a linguistic addition typically attached to names (Al-Khafaji, 2006, p.53).

Some scholars, based on linguistic analysis, believe the city was known as *Kur Babel* around 2000 BCE, meaning "a group of Babylonian villages." It later had several names, including *Nineveh*, *Al-Ghadhiriyah*, and *Karb-ila*, which means "a place of worship" or "temple" in Babylonian. Others trace the word's origin to *Karbalah*, meaning "soft soil" or land known for its pure wheat during cultivation. Another opinion is that the name emerged after the Battle of Ashura (Battle of Karbala), indicating it came into use after the advent of Islam, given that the city hosted the bodies of Imam Hussain and his brother Abbas (peace be upon them). This association with "Karb" (sorrow) and "Bala'" (affliction) led to the city's current name. Karbala has been known by various historical names (Jawad, 2011, p.41), including:

1. **Nineveh**: Given to a location in Karbala after the fall of the Assyrian Empire in 612 BCE, distinct from the famous Nineveh of Ashurbanipal in Mosul.
2. **Al-Taff**: Refers to lands overlooking the Arab territories toward the Iraqi countryside, also known as the riverbank lands due to their proximity to a river that changed course and eventually dried up.
3. **Al-Ghadhiriyat**: Named after *Ghadhira*, a woman from the Arab tribe of Banu Asad, who inhabited the area now north of Hayy Al-Hayyabi.
4. **Al-Nawawis**: Refers to Christian cemeteries located in the northwestern part of present-day Karbala.
5. **Al-Ha'ir (or Al-Hayr)**: Low-lying lands where the holy shrine is situated. Water surrounded the area during the reign of Al-Mutawakkil Al-Abbasi in 236 AH.

Since then, Karbala has become an urban magnet, with people settling around the two holy shrines, forming the first nucleus of a small city. Over time, it expanded, becoming a major religious and commercial hub. The city gradually developed westward due to the presence of orchards and abundant vegetation.

Location

Karbala Governorate is located in the central region of Iraq, on the western edge of the Euphrates River valley, between longitudes 43°–45° E and latitudes 32°–33° N. It is bordered by:

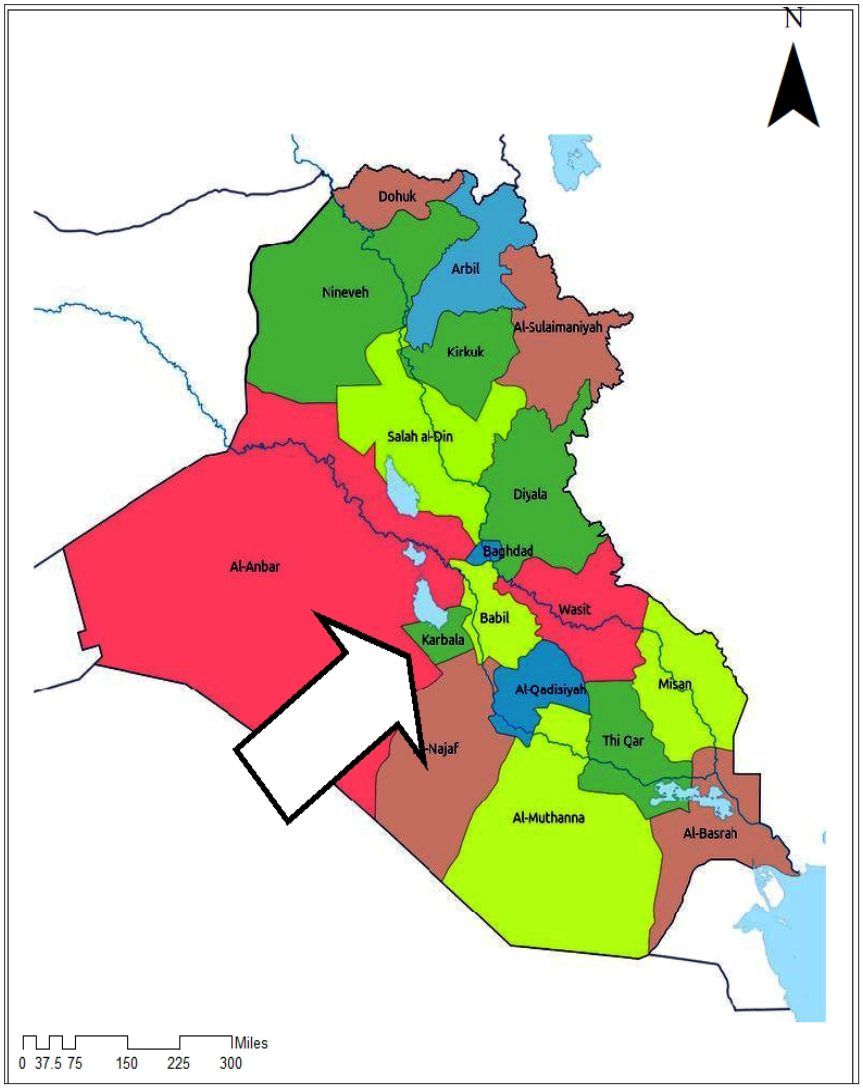
- **North and West**: Al-Anbar Governorate (112 km away)
- **East**: Babylon Governorate (45 km away)
- **South**: Al-Najaf Governorate (74 km away)
- Karbala lies about 89.5 km southwest of Baghdad.

Administrative Borders of Karbala Governorate:

- **North:** Al-Anbar Governorate
- **South:** Al-Najaf and Al-Anbar Governorates
- ***East:*** Babylon Governorate
- **West:** The Northern Desert and part of Al-Anbar Governorate

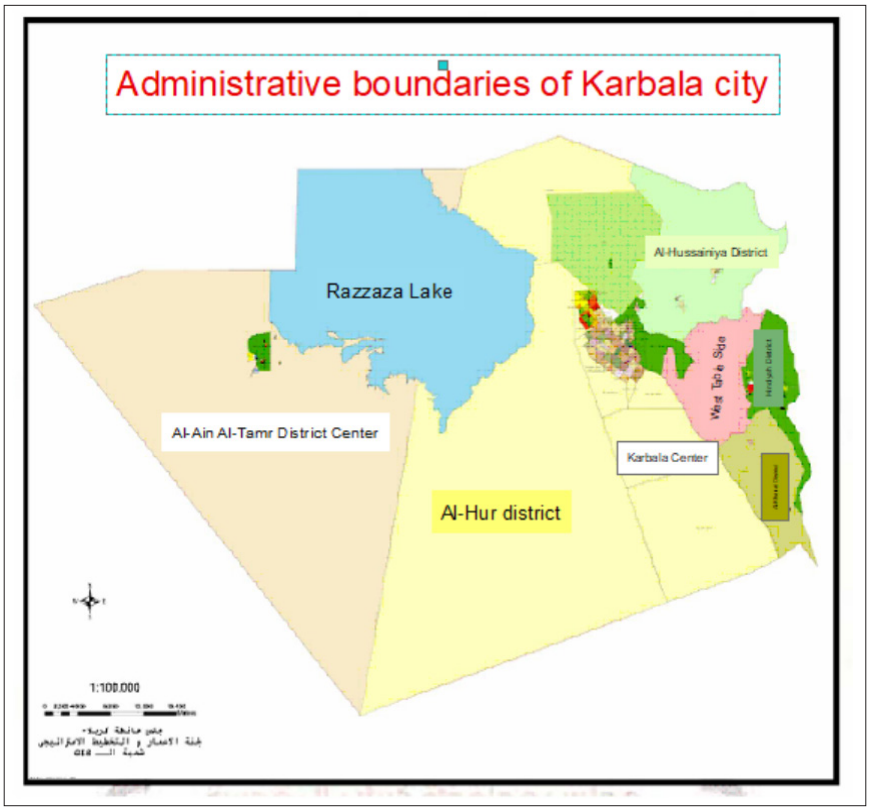
The terrain gradually slopes toward the sedimentary plain in the direction of the Euphrates River Valley. Most of its land is flat and sandy, generally unsuitable for agriculture, except for some areas in the north and east.

Figure 1: Location of Karbala relative to Iraq



Source: Directorate of Urban Planning – Karbala

Figure 2: Administrative Boundaries of the City of Karbala



Source: Karbala Directorate of Urban Planning

Area:

The area of Karbala Governorate is estimated at approximately 5,043 km², representing 1.1% of Iraq's total area of 434,934 km². It consists of three districts:

A. Al-Hindiya District Center: Covers an area of 12 km². It administratively includes:

- Al-Khayrat Subdistrict with an area of 145 km²
- Al-Jadwal Al-Gharbi Subdistrict with an area of 187 km²

Thus, the total area is 344 km².

B. Karbala District Center: Covers an area of 2,397 km². It administratively includes:

• Al-Husseiniya Subdistrict with an area of 337 km²

C. Ain Al-Tamur District Center: Covers an area of 1,956 km² and does not include any subdistricts.Waste Index by Neighborhoods – Table 3

Table 3: Waste Index by Neighborhoods

No.	Indicator	2024 Value	2030 Target
1.	Percentage of neighborhoods where waste is collected once per day relative to the total number of neighborhoods	69%	100%
2.	Amount of collected waste relative to the total daily generated waste	60%	91%

Source: Data from Karbala Municipality Directorate

Religious Occasions in Karbala:

Karbala has gained a distinguished status in Islamic history since the Battle of al-Taff (61 AH / 682 CE), where its soil embraced the shrine of Imam Hussein ibn Ali and his brother Abbas (peace be upon them), as well as their family members and companions who were martyred in the battle. Since then, Karbala has steadily grown and flourished. According to Al-Amar (2005, p. 65), the city faces pressure in providing services during religious occasions due to the large number of visitors coming to visit the holy shrines. This increase necessitates the provision of services, in addition to the problems arising from the influx of vehicles into the city.

Religious occasions represent significant historical and spiritual events with fixed dates that have become well-known days when pilgrims flock to Karbala to perform pilgrimage rituals. Accordingly, it becomes essential to provide sufficient spaces to accommodate the visitors and deliver

the necessary services during their stay in the city. Covered areas or temporary accommodations near the two shrines should be provided to shelter the visitors due to the overcrowding on the surrounding sidewalks and the open space between the shrines.

Visitors can be categorized as follows:

A. **Local Visitors:**

Those coming from within the country, making up about **90%** of the total number of visitors during each religious occasion.

B. **B. Foreign Visitors:**

1. **International Visitors:** Those arriving from non-Arab foreign countries, representing **8–8.5%** of the total visitors.
2. **Arab Visitors:** Those coming from Arab countries, representing approximately **1.5–2%** of the total.

C. **Total Number of Visitors:**

The number of visitors during religious occasions exceeds **21 million** (approximately), while the weekly visits reach more than **half a million** visitors. Table (4) illustrates these estimations:

Table (4): Estimated Number of Visitors to Karbala

Hijri Year	Number of Visitors
1438 Hijri	11,210,367
1439 Hijri	13,874,818
1439 Hijri	13,874,818
1440 Hijri	15,322,948
1441 Hijri	15,229,955
1442 Hijri	14,443,308
1443 Hijri	16,327,542
1444 Hijri	21,198,640
1445 Hijri	21,480,525

Source: Al-Ameedy, Al-Baghdadi, 2025, p. 318

The neighborhoods adjacent to the two shrines were selected as follows:

The research focuses on the center of Karbala **district (Qadha' Karbala)** as the most crowded spatial area during the Arbaeen pilgrimage, and includes the historical neighborhoods surrounding the holy shrines. This clarification emphasizes that the study is limited to the district level, not the entire governorate.The center of Karbala district today consists of eight outskirts (neighborhoods), as shown in Table No. (5) and Figure No. 3. These are the same names of the gates that were in the old wall that surrounded the old city (Al-Ameedy, Al-Baghdadi, p. 324, 2024).

Table (5) shows the most important shops in Karbala.		
No.	Neighborhood Name	Description
1	Bab Al-Sallama	Named after the Arab tribe that inhabited it (Al-Sallama). It is located north of the shrine of Imam Hussain (peace be upon him).
2	Bab Baghdad	Located north of the shrine of Al-Abbas (peace be upon him). This neighborhood is the route travelers take to Baghdad. It is also known as Bab Al-Alwa, named after the vegetable market called Alwa.
3	Bab Al-Taq	Located in the northwest of the city and named after the arch of Sayyid Ibrahim Al-Za'farani, one of Karbala's figures involved in the Manakhour incident in 1241 AH (1823 AD).
4	Bab Al-Khan	Located on the eastern side of the city and named after a large caravanserai (khan) that was built near the city walls.
5	Al-Mukhayyam (The Camp)	Located southwest of the two holy shrines, named after the Hussaini camp that existed there.
6	Bab Al-Najaf	Located in the heart of the city, covering the area between the two holy shrines. It is the neighborhood through which travelers pass when going to Najaf.
7	Al-Abbasiya	Located south of the city, established during the era of the governor Medhat Pasha, known as the "new area." It is divided into two parts: Eastern Abbasiya, east of Abbas Street, and Western Abbasiya, west of Abbas Street.

Figure (3) / A plan of the city center of Karbala, showing the names of the locations of the shops in the city.Source: The Urban Renewal Study of the City Center of Karbala, Phase II, 2011, p. 86

Table 6 shows the types of solid waste common during the Arbaeen Pilgrimage in Karbala

No.	Type of Waste	Contextual Notes
1	Food leftovers and field meals	Produced by feeding convoys; considered one of the most common types of organic waste.
2	Vegetable and fruit peels	Increase due to fruit distribution at hospitality and blessing stations.
3	Plastic, glass, and paper containers	Result from drinking water and juices; crowd size contributes to their multiplication.
4	Abandoned clothes and personal belongings	Left behind by visitors due to fatigue or changing weather conditions.
5	Damaged toys and recreational items for children	Usually left in the squares or lost during large crowds.

Source: Researchers based on field survey

Analyzing the Level of Achievement of AI Standards in Crowd Waste Management During the Arbaeen Pilgrimage in Karbala

Based on a review of the basic standards for AI use in waste management, which include: accuracy, technical integration, scalability, environmental efficiency, ethics, cybersecurity, and governance, it is possible to observe variations in the extent to which these standards are met when applied to the Karbala experience during the Arbaeen pilgrimage.

- Integration with Smart Infrastructure: These are still not fully operational, as Karbala lacks Internet of Things (IoT) networks or LoRa systems that facilitate real-time tracking.
- Scalability: These represent a challenge, as traditional systems are unable to handle sudden surges in waste volume.
- Environmental and Economic Efficiency: These are low, as traditional waste collection methods are used without investment in converting waste into energy or composting.

- Cybersecurity: Not effectively addressed due to the absence of intelligent data management systems.
- Governance: Digital coordination between service providers is lacking, despite significant human efforts.

Here is a comparison table showing the extent to which AI standards were met in managing crowd waste during the Arbaeen pilgrimage in Karbala, based on the previous analysis (Table 7).

Table 7: Analysis of the level of achievement of the criteria for using artificial intelligence in managing crowd waste during the Arbaeen pilgrimage in Karbala

Criterion	Verification Level in Karbala	Notes
Integration with Smart Infrastructure	Almost Absent	No IoT or LoRa networks available for real-time waste monitoring.
Scalability	Limited	Current systems cannot handle surges in waste volume during peak times.
Environmental and Economic Efficiency	Low	No effective investment in recycling or waste-to-energy conversion.
Cybersecurity	Not Enabled	No smart data management requiring information protection.
Good Governance	Weak	Poor digital coordination among service agencies; reliance on field coordination.

Source: Researchers based on field survey

These indicators highlight the need for an integrated strategy to employ artificial intelligence in managing religious crowd waste, contributing to transforming the environmental challenge into a smart and sustainable urban opportunity.

Table 8 shows the extent to which AI standards were applied in waste management in eight locations within the Karbala Historic Center during the Arbaeen pilgrimage, based on a field survey analysis.

Table 8: Application of AI Standards in Waste Management

Neighborhood	Digital Integration	Scalability	Environmental Efficiency	Cybersecurity	Good Governance
Bab Al-Sallama	X	X	X	X	X
Bab Baghdad	X	X	X	X	X
Bab Al-Taq	X	X	X	X	X
Bab Al-Khan	X	√ Partially	X	X	X
Al-Mukhayyam (Camp)	X	√ Partially	X	X	X
Bab Al-Najaf	X	X	X	X	X
Al-Abbasiya	X	√ Partially	√ Partially	X	X

Source: Researchers based on field survey

√: Partially: Indicates the presence of some traditional indicators (such as repeated field efforts, manual monitoring, or temporary coordination).

X: No systems or efforts can be effectively linked to AI standards.

By analyzing the extent of implementation of AI standards in waste management across Karbala, it is clear that the city is still in a very early stage of adopting these technologies. Despite the environmental and spatial challenges posed by the Arbaeen pilgrimage, there is still no integrated digital infrastructure that enables AI systems to operate effectively.

At the level of the eight historic neighborhoods in the Karbala Center, the results showed significant variations in achieving the standards. Most efforts were based on traditional or semi-digital procedures, without actual reliance on advanced AI technologies. The most prominent observations can be summarized as follows:

- A near-total absence of digital integration and smart infrastructure such as IoT or automated data analysis.
- Some neighborhoods (such as Bab al-Khan and Abbasiya) were limited to partial efforts that show signs of expansion or organization, but fall short of global AI standards.

- Governance, transparency, and cyber standards are almost absent, weakening the ability of any digital system to achieve sustainability and accountability. This indicates that achieving smart and sustainable waste management during the Arbaeen season requires a comprehensive institutional and technological transformation, starting with restructuring monitoring, tracking, and decision-making systems based on scalable technology that can be integrated with urban infrastructure.

Arbaeen: Towards an Automated and Sustainable Urban System

With the escalating challenges associated with waste management due to the massive expansion of the millions of pilgrims who visit Karbala during the Arbaeen pilgrimage, the use of artificial intelligence has become an urgent urban necessity to achieve efficiency and sustainability. However, to implement these technologies effectively in Karbala, it is essential to consider current infrastructure limitations, governance coordination challenges, and resource availability. The most prominent mechanisms adopted or possible for implementing these technologies are as follows:

1. Smart robots for waste collection and sorting:

Robots equipped with computer vision and AI technologies can automatically identify and sort waste (organic, plastic, metal, etc.). In Karbala, this solution could be introduced as a pilot program in high-density zones near the shrines. Yet, the lack of advanced power supply systems and the need for skilled maintenance teams are key challenges that must be addressed through public-private partnerships.

Figure 4: Robot collecting and sorting waste

Figure 4: Robot collecting and sorting waste

2. **Connected smart containers:**

These containers use sensors to monitor waste levels and report data to central systems. In Karbala, integrating such bins in main pilgrim gathering points (like Bab Baghdad Street or Al-Abbas Street) can reduce overflow. However, the limited internet coverage and real-time data infrastructure necessitate a phased approach and possible reliance on offline-capable systems or LoRaWAN networks.

Figure 5: Smart, internet-connected, solar-powered waste containers

Figure 5: Smart, internet-connected, solar-powered waste containers

3. **Drones:** Drones can monitor waste hotspots and crowd density. In Karbala, their use could enhance real-time monitoring of zones with heavy foot traffic. However, regulatory constraints and limited operational zones (due to security around the shrines) require coordination with local authorities and security forces.

.Figure 6: Drones

Figure 6: Drones:

4. **Smart Waste Collection Route Systems:**

AI-driven route planning can reduce vehicle congestion and fuel use. In Karbala, this system could be tested with the municipal fleet, particularly during peak visitation. Still, aging vehicles, lack of GPS-enabled tracking, and weak coordination between cleaning departments remain implementation barriers. Pilot programs with external support or donor funding may provide a feasible entry point.

Figure 7: Smart waste management

Figure 7 Smart waste management

5. Predictive Platforms and Central Control:

These systems analyze data to forecast waste generation and coordinate response teams. For Karbala, establishing a central operations room during the pilgrimage season could significantly improve coordination. However, existing fragmentation between municipal departments and limited data integration mechanisms pose significant obstacles, calling for inter-agency collaboration protocols and capacity-building.

Figure 8:

Figure 8 Predictive platforms and central control

6. Smart Waste Segregation Systems:

Waste segregation is a crucial step in sustainable waste management. Color-coded containers (for organic, glass, plastic, paper, etc.) are designed and connected to smart systems that track waste filling rates and type. This mechanism contributes to promoting recycling, reducing random pollution, and increasing visitor awareness through a simple, easy-to-use visual system. Figure 9 Using color-coded, sensor-equipped bins in Karbala's temporary camps and main routes can promote recycling and reduce waste volume. Educational signage in multiple languages can enhance awareness. Yet, low public engagement in waste separation and absence of recycling infrastructure requires a long-term strategy involving awareness campaigns, partnerships with NGOs, and mobile recycling stations.

Figure 9: Intelligent garbage sorting box

Figure 9 Intelligent garbage sorting box is an equipment or device to realize automatic garbage sorting and collection.

Conclusions

1. Traditional systems are unable to effectively manage waste during the Arbaeen pilgrimage.
2. There is no actual implementation of AI technologies in the waste management system.
3. Institutional coordination between service providers is lacking during the pilgrimage season.
4. Waste is collected in a mixed form without any source separation.
5. Smart digital infrastructure is not activated in the city of Karbala.
6. There is an urgent need for technological solutions to address environmental pressure during the pilgrimage.

Recommendations

First: Technical Recommendations

1. Deploy smart waste bins equipped with sensors and automatic sorting Responsible Entity: Karbala Municipality + Private Tech Companies Feasibility: Medium-term
2. Use AI-based predictive systems to monitor waste volume and distribution.Responsible Entity: Karbala Municipality + University Labs Feasibility: Short-term
3. Equip transfer stations with robotic arms for automatic waste sorting. Responsible Entity: Ministry of Construction and Housing Feasibility: Long-term
4. Use drones to monitor waste accumulation sites in real time. Responsible Entity: Environmental Directorate + Civil Defense Feasibility: Medium-term

Second: Institutional Recommendations

1. **Establish a smart monitoring center for waste management during Arbaeen.**

- Responsible Entity: Karbala Municipality + Ministry of Communications.
- Feasibility: Medium-term.

2. **Form a local coordination council including the municipality, holy shrines, universities, and private sector.**

- Responsible Entity: Karbala Governorate.
- Feasibility: Short-term.

3. **Update municipal regulations to support the integration of AI technologies in services.**

- Responsible Entity: Provincial Council + Legal Affairs Department.
- Feasibility: Medium-term.

4. **Allocate an annual budget for AI-based waste management projects.**

- Responsible Entity: Ministry of Planning + Karbala Municipality.
- Feasibility: Medium-term.

Third: Community-Based Recommendations

1. **Launch a digital awareness app to guide pilgrims on smart waste practices.**

- Responsible Entity: NGOs + App Developers
- Feasibility: Short-term

2. **Implement on-site awareness campaigns at service stations on smart waste disposal.**

- Responsible Entity: Municipality + Local Volunteers
- Feasibility: Short-term

3. **Support graduation projects and academic research on AI and waste management.**

- Responsible Entity: Ministry of Higher Education + University of Karbala
- Feasibility: Short-term

4. **Apply a source-based waste separation system around the shrine area.**

- Responsible Entity: Karbala Municipality + Field Awareness Teams
- Feasibility: Short-term

References

1. Peña J M 2018 Reasoning with alternative acyclic directed mixed graphs Behaviormetrika 45 389–422 .
2. 15. Sarowa S, Singh H, Agrawal S and Sohi B S 2018 Design of a novel hybrid intercarrier interference mitigation technique through wavelet implication in an OFDM system Digit. Commun. Networks 4 258–63.
3. AI application for solid waste sorting in Global South Thien-An Tran Luu, Hong-Minh Le, Minh-Quyen Vu, Bich-Van Nguyen (Văn Lang Private University, Vietnam).
4. Al-Ameedee ,Rashid ,Raghad Mahdi Muoslim and Abdul Sahib Naji , Sustainable development of historical areas: study of one of the global experiences, arth and Environmental Science, Earth Environ. Sci. 1129 012024 1129 (2023) 012024 IOP Publishing doi:10.1088/1755-1315/1129/1/012024, ,2024.
5. Almeedy, Al-Baghdadi, Raghad Mahdi Muslim, Abdul Sahib Naji, Adaptive Reuse of Historic Buildings for the Purposes of the Arbaeen Pilgrimage of Imam Hussein (peace be upon him) ISSN: 2959-1228, Al-Arbaeen Journal, a peer-reviewed scientific journal, published in March 2024, Part Two 2024.
6. Almeedy, Raghad Mahdi Muslim, “Urban Sustainability of His-

toric Buildings and Areas in the Old City of Najaf," Master's Thesis, College of Urban Planning, University of Kufa, 2023.

7. Almeedy, Raghad Mahdi Muslim, Higher Diploma Project, (Methods and Mechanisms of International Conventions for Preserving the Identity and Heritage of Iraqi Cities - The Old City of Najaf as a Model) College of Urban Planning, University of Kufa 2019.
8. Al-Ammar, Ali Karim Abboud, PhD thesis entitled: "Foundations for Calculating Spatial Economic Relationships Between Governorates (Quantitative Analysis Methods for Interregional Areas) An Applied Study of the Governorates of (Babil, Karbala, and Najaf)", Higher Institute of Urban and Regional Planning, 2005. 9. Almeedy, Al-Baghdadi, Raghad Mahdi Muslim, Abdul Sahib Naji, Urban Sustainability of the Historic Center of the Holy City of Karbala as a Framework for Enhancing the Arbaeen Pilgrimage of Imam Hussein (peace be upon him) ISSN: 2959-1228, Al-Arbaeen Journal, a peer-reviewed scientific journal, published in Volume Two - Issue Two - Part Five - Section One - Year Two Ramadan 1446 - March 2025.
9. Al-Baghdadi, Almeedy, Abdul-Sahib Naji, Raghad Mahdi Muslim, Historic Buildings in the Old City of Najaf: The Holy Al-Haidari Shrine and Its Annexed Historic Buildings as a Model (An Evaluative Study of International Conservation Standards and the Najaf Charter), Volume 1, Issue 78 (2024): Journal of the Islamic University College, 2024.
10. Al-Baghdadi, Almeedy, Abdul-Sahib Naji, Raghad Mahdi Muslim, Mechanisms for the Preservation of Historic Buildings in Iraqi City Centers, The Historic Center of Najaf as a Model, An Applied Study of International Preservation Standards and the Najaf Charter for Historic Buildings, Book, First Edition, Dar Abu Talib, 2019.
11. Al-Baghdadi, Almeedy, Abdul-Sahib Naji, Raghad Mahdi Muslim, Mechanisms for the Preservation of Historic Buildings in Iraqi City Centers, The Historic Center of Najaf as a Model, An Applied Study of International Preservation Standards and the Na-

jaf Charter for Historic Buildings, Book, Second Edition, Dar Abu Talib, 2023.

12. Al-Baghdadi, Almeedy, Abdul-Sahib Naji, Raghad Mahdi, Heritage Buildings in the Historic Center of Najaf: (Al-Buraq Neighborhood as a Model) - An Applied Study of International Preservation Standards and the Najaf Charter for Heritage Buildings, Volume 2020, Issue 42, Vol. 1 (March 31, 2020), pp. 11-48, 38pp., University of Kufa, College of Arts, Kufa Journal of Arts, March 31, 2020.
13. Al-Khafaji, Hala Hussein Musa, Master's Thesis entitled: "The Impact of Religious Tourism on the Urban Modernization of the City Center of Karbala," College of Engineering, University of Baghdad, Department of Architecture, 2006. 7. Department of Urban Planning, Karbala Governorate.
14. Ascher S, Watson I, You S (2022) Machine learning methods for modelling the gasification and pyrolysis of biomass and waste. Renew Sustain Energy Rev 155:111902. https:// doi. org/ 10. 1016/j. rser.2021.111902 .
15. Aydın Temel F, Cagcag Yolcu O, Turan NG (2023) Artificial intel ligence and machine learning approaches in composting pro cess: a review. Biores Technol 370:128539. https:// doi. org/ 10. 1016/j. biortech.2022.128539.
16. B. Fang, J. Yu, Z. Chen, A. I. Osman, M. Farghali, I. Ihara, E. H. Hamza, D. W. Rooney, and P.-S. Yap,."Artificial intelligence for waste management in smart cities: a review," Environmental Chemistry Letters, Apr. 2023. doi: 10.1007/s10311-023-01604-3.
17. Chen L, Huang L, Hua J, Chen Z, Wei L, Osman AI, Fawzy S, Rooney DW, Dong L, Yap P-S (2023) Green construction for low-carbon cities: a review. Environ Chem Lett. https:// doi. org/ 10. 1007/ s10311-022-01544-4.
18. Chen X, Huang H, Liu Y, Li J, Liu M (2022b) Robot for automatic waste sorting on construction sites. Autom Constr 141:104387. https://doi.org/10.1016/j.autcon.2022.104387

19. Development Project of the Area Between the Two Shrines, Karbala Governorate, Urban Planning Department of Karbala Municipality, 1977.

20. Fadhullah W, Imran NIN, Ismail SNS, Jaafar MH, Abdullah H. Household solid waste management practices and perceptions among residents in the East Coast of Malaysia. BMC Public Health. 2022 Dec;22(1):1.

21. Ihsanullah I, Alam G, Jamal A, Shaik F. Recent advances in applications of artificial intelligence in solid waste management: A Dec;309:136631. review. Chemosphere. 2022

22. J. S. Teoh, M. S. Islam, N. Misran, M. H. Baharuddin, H. Arshad, M. R. Islam, M. E. H. Chowdhury, H. Rmili, and M. T. Islam, "An Internet of Things Based Smart Waste Management System Using LoRa and Tensorflow Deep Learning Model," *IEEE Access*, vol. 8, pp. 148793–148804, Aug. 2020, doi: 10.1109/ACCESS.2020.3016255.

23. Jawad, Salam Abdul-Hussein (2011), "Change in Historic Centers," a study published in the Journal of Planning and Development, Center for Urban and Regional Planning, University of Baghdad, Issue (24), Iraq.

24. Mittal M, Verma A, Kaur I, Kaur B, Sharma M, Goyal L M, Roy S and Kim T-H 2019 An efficient edge detection approach to provide better edge connectivity for image analysis IEEE Access 7 33240–55.

25. Neidhardt J and Werthner H 2018 IT and tourism: still a hot topic, but do not forget IT Inf. Technol. Tour. 20 .

26. Z.-Q. Zhao, P. Zheng, S.-T. Xu, and X. Wu, Object detection with deep learning: A review, IEEETrans.NeuralNetw.Learn. Syst.,vol.30,no.11, pp. 32123232, Nov. 2019. [15] C.-W. Chen, S.-P. Tseng, T.-W. Kuan, and J.-F. Wang, Outpatient text classi cation using attention-based bidirectional LSTM for robot-assisted servicing in hospital, Information, vol. 11, no. 2, p. 106, Feb. 2020.