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SMART TECHNOLOGIES IN HOUSEHOLD SOLID WASTE COLLECTION: REDUCING OCCUPATIONAL RISK FOR COLLECTION WORKERS. A REVIEW.

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Abstract
Background: Household solid waste collection is labor-intensive and high-risk. **Objective:** To describe new technologies reducing occupational risks inherent to this activity. **Methods:** A literature review with (PRISMA) methodology compared the occupational risks solid waste collection workers face in developed and developing nations across Africa, Asia, and Europe that utilize door-to-door waste collection systems and the potential of IoT-based Smart Waste Management Systems to mitigate these risks in household waste collection. The search was carried out through Scopus and Web of Science databases. **Results:** Initially, 2417 items were found in the search databases, of which 24 were included. Door-to-door solid waste collection expose workers to multiple occupational hazards. Implementing IoT-based waste management technologies such as (systems to collect, send, and analyze data from waste collection points with sensors, processors, or communication hardware, presents a promising approach to mitigating these hazards and helping optimize collection routes, reducing physical strain and minimizing direct human contact with waste. However, implementing of these IoT technologies may face challenges, particularly the need to restructure the door-to-door collection system. **Conclusions:** The study highlights the urgent need for innovative solutions to reduce occupational risks and improve working conditions for waste collection workers.

Keywords: Occupational Safety, Waste Collection, Musculoskeletal Disorders, Smart Technologies, Occupational Hazards.

Introduction

The production of waste in various forms solid, gaseous, or liquid, has increased significantly as the population grows, so municipal solid waste collection systems must deal with waste and environmental and esthetic problems (Rajendren *et al*., 2024). Properly managing the tons of waste generated daily has become one of the most pressing challenges of the 21st century. This increase in waste volume is attributed to the rapid growth of the population and the difficulties associated with waste disposal (Fayomi *et al*., 2021). By 2050, global waste generation projected to reach an astonishing 3.40 billion tons, which implies a tripling of current levels (Kasa, Silpa, n.d.).

Households are the primary generators of solid waste. Once the waste is placed on the street, the first stage of the collection begins, which requires human labor to remove it. Although waste collection work contributes to public health systems in many countries (*Decent Work in Waste Management*, 2014), workers in this sector, are exposed to various occupational hazards and unsafe working conditions, as well as face social stigma of discrimination due to the nature of their work (World Health Organization., n.d.).

This study compares IoT (Internet of Things) technology with the door-to-door systems in the waste collection sector. First, in a door-to-door system, different types of waste are collected directly from the user's home (Degli Esposti *et al*., 2023). Workers involved in this method face exposure to several occupational risks, including musculoskeletal disorders, injuries, lacerations from handling waste, and chemical and biological risks (Thakur *et al*., 2018). Despite the challenges, this method remains vital in many countries, serving as the primary system for managing household waste (Maalouf & Agamuthu, 2023).

The second methodology involves an integrated system model for intelligent waste collection based on IoT (Internet of Things) technology. This system employs sensors installed in waste bins to monitor waste levels and transmits data over the Internet to a central server for processing (Gutierrez *et al*., 2015). In contrast to traditional methods, it minimizes direct contact between workers and waste, thereby reducing occupational risks. In fact, a study indicated that just the implementation of solid containers reduced by 70.27% the number of accidents related to sharp materials and falls (Dos Santos *et al*., 2020). It represents a promising seed of change in the field of waste collection, offering a safer and more efficient alternative, which, in fact, should be further studied in future research as there is currently a gap in this area.

There is a marked difference between these two systems, the door-to-door collection system being the most common form of collection in some countries (Door-to-Door Waste Collection › Evreka, 2022), At the same time, IoT technology is often applied in cities around the world that have adopted the smart city model, corresponding to an urban planning model based on the digitization of services, digitization of processes, and decision-making based on data analysis (I. Shah *et al*., 2021).

Adopting IoT-based waste collection systems, in cities that rely on door-to-door methods could significantly improve collection workers' working conditions while contributing to broader public health and environmental goals. This approach underscores the potential for technological solutions to transform essential yet hazardous jobs into safer and more sustainable practices and lays the foundation for their adaptation in other cities worldwide.

In brief, the aim of this work is to present a technological alternative to solid waste collection that is currently being tested. These solutions not only help reduce the occupational risks faced by waste collection workers and offer environmental benefits but also prove to be cost-effective in the long run, as the expenses associated with worker illnesses and injuries often exceed the investment in safer and more efficient waste collection systems.

Materials and Methods

Search Characteristics

The study used a systematic review methodology PRISMA (Page *et al*., 2021), while the eligibility criteria for the initial stage included literature published between 2020 and 2024, using predefined keywords to facilitate the search, and only articles in English. The first stage focuses on IoT technology applied to household solid waste collection, specifically Smart Waste Management Systems, such as smart bin sensors, smart trucks, and region-specific smart bins. The selected keywords included: waste collection, waste, intelligence, smart, musculoskeletal disorders, occupational risks, and health.

In the second stage, a literature search was conducted to identify risk factors affecting solid waste collection workers. Keywords used in this stage included: waste collectors, waste, occupational risks, occupational health, occupational hazards, musculoskeletal disorders, and ergonomics.

In the third stage, the reference management software Zotero (*Zotero | Your Personal Research Assistant*, n.d.) was used to download the databases and conduct an initial screening based on the titles and objectives of the articles. Only those articles meeting the predefined inclusion criteria were selected for further analysis.

Characteristics of Accepted Studies

In the first stage, the search focused on studies related to IoT-based smart waste management systems. Research articles on IoT applications in smart cities were analyzed, particularly those examining the design of smart waste management systems for household solid waste collection using IoT technology. In the second stage, the focus shifted to studies on occupational risks among waste collection workers engaged in physically demanding tasks, such as door-to-door collection. This analysis aimed to establish a reference for the occupational hazards these workers face.

The databases consulted were Scopus and Web of Science; in each database, the filters used were publication year (between 2020 and 2024), type of document (article), type of source (journals), and language (English). The research was carried out from 24 November to 15 December 2024.

The search strategy for IoT includes the combination of the following keywords: ("waste collection" OR waste) AND (intelligence OR smart) AND ("musculoskeletal disorders" OR "occupational risk" OR health) AND NOT "e-waste".

Likewise, the search strategy for the research on occupational risk factors in SWC (Solid waste collection) was: ("waste collectors" OR waste) AND ("occupational risk" OR "occupational health" OR "occupational hazard") AND ("musculoskeletal disorders" OR ergonomics).

Study Records

Data management was carried out by directly downloading information from electronic databases into the reference manager Zotero (Zotero | Your Personal Research Assistant, n.d.), facilitating organization throughout the screening process. The information was transferred to an Excel matrix for further analysis after the screening. In the initial stage, information from electronic databases was imported into Zotero, and a preliminary screening of article titles was conducted to determine their alignment with the study's objectives. The abstract was reviewed if there were doubts about the article's suitability for inclusion. Subsequently, in the second stage, the extracted data were imported into the Rayyan software (Rayyan | Home, n.d.) for duplicate detection, where duplicate articles were screened and removed. The selected articles were then re-imported into the Zotero reference manager. After the initial screening stage, the subsequent evaluation was conducted based on the eligibility criteria. Relevant information was then extracted from the articles to complete a matrix.
Subsequently, an Excel matrix was created, with each row representing a different article and each column corresponding to a parameter or variable extracted from the articles. Information extraction was performed using the SciSpace software (AI Chat for Scientific PDFs | SciSpace, n.d.), followed by manual verification of the content by reading the sections of the articles.
Therefore, the accepted articles were those that m*et al*l these minimum criteria:

- Studies about IoT include (Smart Waste Management Systems: Smart Bin Sensors, Smart Truck, and Region Smart Bin).
- Waste management using IoT using bin based on IoT.
- Smart cities with IoT models of waste management.
- Studies about occupational hazards and risk factors related to SWC. Articles that were focused on other subjects as following were excluded:
- Articles related to evaluating attitudes, risk behavior, and practices of workers; perception of workers (there were no available risk assessment tools); surveys about health and safety programs.
- Articles related to child waste workers.
- Studies focused on recycling plants in informal sectors where the door-to-door collection system does not apply.

Results

The selection process results are shown in Figure 1. Initially, 2417 items were found in the search databases. Then, with the application of search filters such as date, document type, source type, off-topic, and language restrictions, 2372 articles were excluded. Additionally, 13 duplicate records were also removed.
In the screening phase, of the remaining 32 articles, four were excluded for being off-topic (not related to the door-to-door waste collection system and not focused on IoT in the waste collection area), leaving 28 articles for retrieval. Among these, two articles were not available online. In the final step, one article was excluded because the study was unrelated to the scope of the research in waste collection, and one more was excluded as it did not align with the review objectives.
Therefore, 24 articles were identified as relevant publications for the present study; of these, 17 pertain to smart technologies proposed in SWC, and seven focus on risk factors affecting solid waste collection workers.

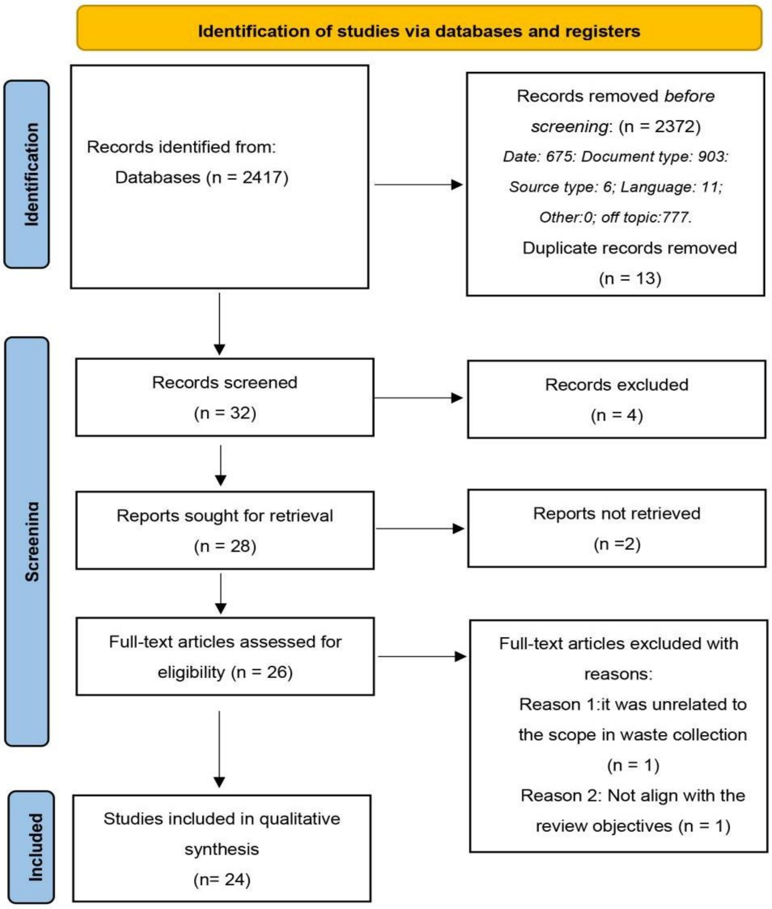

Figure 1. *PRISMA 2020 Flow Diagram of the research (Page et al., 2021).*

Study characteristics

Smart technologies in solid waste collection system

The selection process results are shown in Table 1. In terms of geographical distribution, most studies were conducted in Asia (94.12%) and Africa (5.88%). The main smart devices used in waste management for smart cities were IoT-based smart bins with fill-level sensors for garbage management (Abba & Light, 2020; Abidin *et al*., 2022; Abuga & Raghava, 2021; Addas *et al*., 2024; Bhowmik *et al*., 2020; A. Hussain *et al*., 2020, 2020; I. Hussain *et al*., 2024; Joshi *et al*., 2022; Lama & Karmakar, 2024; Okubanjo *et al*., 2024; Ramson *et al*., 2021; Sung *et al*., 2022; Vishnu *et al*., 2021; Zhang *et al*., 2020), which allow real-time monitoring of bin fullness levels and the creation of optimized daily collection routes, likewise IoT-based camera sensors for data collection (Al Duhayyim *et al*., 2022). Weight sensors for waste measurement *(I. Hussain et al., 2024; Zhang et al*., 2020) and real-time communication between waste bins and collection vehicles (Abba & Light, 2020; Addas *et al*., 2024; Bhowmik *et al*., 2020; I. Hussain *et al*., 2024; Ramson *et al*., 2021; Sung *et al*., 2022; Zhang *et al*., 2020).

With respect to the implementation of IoT-based waste management, the research findings were categorized into the following subjects:

- *Accuracy*: Effectiveness and functionality of smart bins.
- *Air pollutant prediction*: Effective measurement of air pollutants.
- *Automation*: Facilitates real-time monitoring of garbage bin levels and minimizes human contact with waste.
- *Optimization*: Improves sorting efficiency.

The relative frequency results for these subjects found in the studies are presented in Figure 2. It is observed that most studies reported findings about optimization (37.96%) and automation (31.03%).

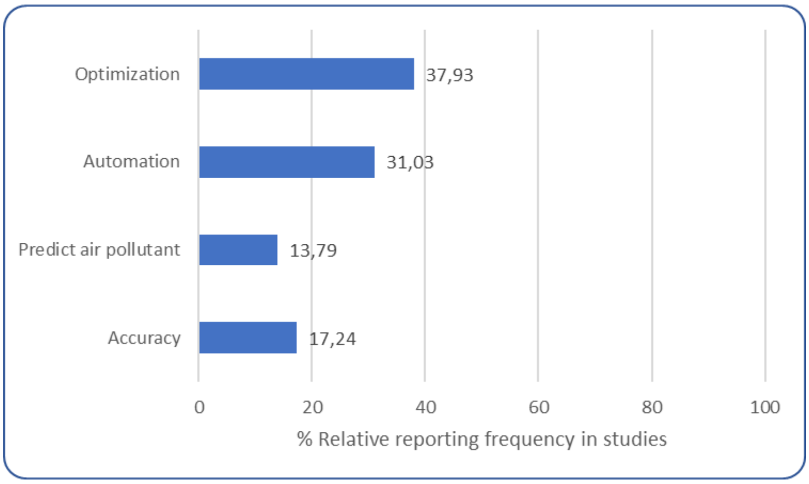

Figure 2. *Results obtained from the implementation of IoT-based waste management.*

Table 1. *Smart technologies proposed in solid waste collection.*

Title/Reference	Country	Technology used	
		Device/technique	**Characteristics**
Waste management and prediction of air pollutants using IoT and machine learning approach. (A. Hussain *et al.*, 2020)	Pakistan	Smart bin for garbage management	-Machine learning models for predicting bin status. -Deep learning for forecasting air pollutants.
Smart garbage bin based on AIoT. (Sung *et al.*, 2022)	Taiwan	-A prototype smart garbage.	-A Bluetooth signal tracks the smart garbage bin's location
Artificial Ecosystem-Based Optimization with an Improved Deep Learning Model for IoT-Assisted Sustainable Waste Management. (Al Duhayyim *et al.*, 2022)	Saudi Arabia	-IoT-based camera sensors for data collection, model AEOIDL-SWM technique.	Microcontroller for data processing
An Intelligent Waste Removal System for Smarter Communities. (Zhang *et al.*, 2020)	China	-Smart bin -Weight sensor - RRT algorithm. -ROS operating system	-Microcontroller for data processing -Weight sensor for measuring garbage weight. -Algorithm for path planning in waste collection vehicles. - ROS operating system for intelligent waste disposal process automation.
Smart trash bin for management of garbage problem in society. (Abidin *et al.*, 2022)	Indonesia	-Smart bin - (WCVs)	-Full bins notify cleaners via Telegram messages. -The lid opens automatically when approached.
Smart bin and IoT: a sustainable future for waste management system in Nigeria. (Okubanjo *et al.*, 2024)	Nigeria	-Bin with ultrasonic sensors. -Wi-Fi module for data transmission.	Ultrasonic sensors for object detection and waste level monitoring.
Secure waste collection approach for smart cities. (Lama & Karmakar, 2024)	India	-AVISPA tool -Smart bin	-AVISPA for security analysis.

Title/Reference	Country	Technology used	
		Device/technique	**Characteristics**
Design and development of smart Internet of Things-based solid waste management system using computer vision. (Mookkaiah *et al*., 2022)	India	- (CNN) for waste classification	Machine learning techniques: regression, classification, clustering, correlation rules.
Real-time smart garbage bin mechanism for solid waste management in smart cities. (Abuga & Raghava, 2021)	India	-Smart bin	-Smart Garbage Bin Mechanism. - Net Logo platform
Real time monitoring of solid waste with customized hardware and Internet of Things. (Joshi *et al*., 2022)	India	-Smart bin -Ultrasonic sensors	- Garbage levels are indicated by colored lights. -Sensor nodes communicate data to the cloud server.
IoT-Enabled solid waste management in smart cities. (Vishnu *et al*., 2021)	Not available	-Smart bin	-Public Bin Level Monitoring
IoT (Internet of Things) -Based smart garbage management system: a proposal for major cities of Bangladesh. (Bhowmik *et al*., 2020)	Bangladesh	-Smart bin	- Real-time data transmission to central server. - Smart bins will have sensors for garbage level detection.
IoT-Based framework for smart waste monitoring and control system: a case study for smart cities (Abba & Light, 2020)	Not available	-Smart bin. -Ultrasonic sensors	-Ultrasonic sensors detect garbage levels in bins. -IoT-based Arduino microcontroller for waste monitoring.
Waste management 2.0 leveraging internet of things for an efficient and eco-friendly smart city solution. (Addas *et al*., 2024)	Pakistan	- Smart bin. -Ultrasonic Sensors.	-Ultrasonic Sensors: to measure the distance to the waste within the garbage bins. -Dynamic route optimization algorithms for collection efficiency
An IoT-based bin level monitoring system for solid waste management. (Ramson *et al*., 2021)	Not available	- (BLMU). - Smart graphical (SG) user interface.	-(BLMU) for trash bins -SG user interface for monitoring.
An internet of things based smart waste system. (Jasim *et al*., 2021)	Iraq	-Wi-fi Micro controller. - Ultrasonic sensors	-Ultrasonic sensors for waste level measurement.
Smart city solutions: comparative analysis of waste management models in IoT-enabled environments using multiagent simulation. (I. Hussain *et al*., 2024)	Qatar	-Smart bin -Ultrasonic and weight sensors	- Ultrasonic and weight sensors. - Real-time monitoring with IoT-connected waste bins.

Abbreviation: IoT: Internet of things; ROS: Route operation system: RRT: Rapid exploration of random trees; WCVs: Waste collection vehicles. CNN: Convolutional Neural Network; BLMU: Bin Level Monitoring Unit. AVISPA: Automated Validation of Internet Security Protocols and Applications; AEOIDL-SWM: artificial ecosystem-based optimization with an improved deep learning model for IoT-assisted sustainable waste management.

Occupational Safety and Health Assessment of Solid Waste Collection Workers

Studies in occupational risks among solid waste collection workers are summarized in Table 2. The studies showed waste collection workers were exposed to several occupational risk factors. First, regarding ergonomic risks, the tasks performed by the workers were categorized as follows: repetitive tasks (Hossain *et al*., 2024;

Kaphle *et al*., 2024; Ziaei *et al*., 2019), lifting, loading, and carrying waste (Elsayed Farid Amr & Abdel Malek Hussein, 2021; Sangkham *et al*., 2021; Ziaei *et al*., 2019), pulling and pushing (Rossi *et al*., 2022; Ziaei *et al*., 2019). Additionally, awkward postures were analyzed in two studies (Kaphle *et al*., 2024; Van Nguyen *et al*., 2020). These factors could be directly associated with the musculoskeletal disorders (MSDs) reported in all studies. Studies indicated that the main consequences of these ergonomic risks included chronic back pain (Rossi *et al*., 2022) and inflammatory conditions (muscles, tendons, nerves, joints, ligaments) *(Van Nguyen et al*., 2020; Ziaei *et al*., 2019).

Furthermore, studies indicated that waste collectors were exposed to multiple occupational risks due to the complex nature of their work. These included physical, chemical, biological, mechanical, and psychological risks, which contributed to the development of various occupational diseases, such as gastrointestinal tract infections and skin allergies (Hossain *et al*., 2024; Kaphle *et al*., 2024; Sangkham *et al*., 2021).

Table 2. *Risk factors affecting solid waste collection workers.*

Title/Reference	Country	Population sample	Main Work Task	Occupational risk	Type of disease found
Occupational health problems among waste collectors in a metropolitan city: a cross-sectional study. (Kaphle *et al*., 2024)	Nepal	158 household waste collectors	Street cleaners and solid waste workers, who perform repetitive physical tasks and awkward postures.	Physical, biological, ergonomic, psychological	MSDs: physical injuries, gastrointestinal tract infections, skin allergies.
Occupational health hazards and the use of safety protective measures among municipal solid waste collectors. (Elsayed Farid Amr & Abdel Malek Hussein, 2021)	Egypt	140 municipal solid waste collectors	Cleaning the streets, caring for and lifting solid waste. Evacuate refuse containers into trucks.	Physical, chemical, biological, mechanical, ergonomic, psychological.	Respiratory diseases, skin problems, stomach infections, MSDs: back pain.
Occupational health hazard exposure and health problems among solid waste collectors in Phayao Province, Northern Thailand. (Sangkham *et al.*, 2021)	Thailand	107 solid waste collectors	Lifting and loading waste from containers and pick-up locations.	Physical, chemical, biological, ergonomics, mechanicals, psychosocial.	MSDs: musculoskeletal pain, respiratory and skin diseases.
Musculoskeletal pain and work-related risk factors among waste collectors in Hanoi, Vietnam: a cross-sectional Study. (Van Nguyen *et al.*, 2020)	Vietnam	468 waste collectors	Awkward postures.	Physical, ergonomics, Psychosocial.	MSDs: inflammatory conditions affecting the supporting blood vessels, nerves, joints, ligaments, and muscles.
Health challenges among waste collectors in Bangladesh: exploring risk factors using multi-level modeling. (Hossain *et al.*, 2024)	Bangladesh	481 waste collectors	Repetitive and physically demanding activities	Physical, chemical, biological, mechanicals, psychosocial.	Gastrointestinal, dermatological diseases. MSDs: chronic pain conditions

Title/Reference	Country	Population sample	Main Work Task	Occupational risk	Type of disease found
A comparison of different waste collection methods: Environmental impacts and occupational risks. (Rossi *et al*., 2022)	Italy	Not specify sample size	Pulling bins towards the compactor, hooking the bin, activating the automatic emptying system, unhooking the bin, and pushing it back to its original location.	Ergonomics, psychosocial.	MSDs: back pain, chronic pain conditions in back, neck, shoulders, and limbs.
Psychological and physical job demands, decision latitude, and work-related social support among Iranian waste collectors. (Ziaei *et al*., 2019)	Iran	200 waste collectors	Lifting and carrying waste containers, pulling heavy loads, and performing repetitive tasks.	Ergonomics and physical.	MSDs: including tendons, ligaments, cartilage, muscles, and nerves. Respiratory problems, and cardiovascular diseases

Abbreviation:MSDs (musculoskeletal disorders)

Discussion

Studies on occupational hazards among waste collection workers were mainly conducted in Asia countries (Hossain *et al*., 2024; Kaphle *et al*., 2024; Sangkham *et al*., 2021; Van Nguyen *et al*., 2020; Ziaei *et al*., 2019), where mainly door-to-door collection is employed. Only one study (Rossi *et al*., 2022) was conducted in Europe and another one in Africa (Elsayed Farid Amr & Abdel Malek Hussein, 2021). These studies demonstrate that the SWC door-to-door system is a high-risk occupation due to the various work-related diseases reported as a consequence of this activity *(Elsayed Farid Amr & Abdel Malek Hussein, 2021; Kaphle et al., 2024; Ziaei et al*., 2019). Additionally, some studies reported psychosocial risks among workers (Elsayed Farid Amr & Abdel Malek Hussein, 2021; Hossain *et al*., 2024; Kaphle *et al*., 2024; Rossi *et al*., 2022; Sangkham *et al*., 2021; Van Nguyen *et al*., 2020; Ziaei *et al*., 2019), which could be associated with exposure to ergonomic hazards, as all studies reported. The consequences observed in workers were not only physical but also psychological.

Implementing technologies such as IoT-based waste management in this field enables task automation, and reduces workload. The placement of smart bins in strategic locations could help decrease occupational risk exposure. In fact, one study mentions that the door-to-door collection method exposes workers to high risks, which could be mitigated with the use of smart technologies (Jasim *et al*., 2021). The level of ergonomic risk decreases as forced postures, repetitive tasks, and heavy lifting and dragging are eliminated with smart technology implementation. Another advantage of this technology is its environmental contribution, as it enhances the automation of waste sorting tasks (Abidin *et al*., 2022) and improves the accuracy of gas concentration monitoring in smart bins (I. Hussain *et al*., 2024).

Nevertheless, implementing IoT-based waste management systems in countries with door-to-door collection models, where mechanical, physical, chemical, ergonomic, biological, and psychosocial hazards are prevalent, may encounter several challenges. These challenges include the need to restructure the existing collection system, which would significantly increase costs related to technological investments and the public's re-education on new collection procedures. However, studies indicate that the cost-benefit ratio of maintaining this technology is justified by the advantages it brings to waste collection systems, particularly in smart cities (I. Hussain *et al*., 2024). These benefits include environmental sustainability, gas emission monitoring, and process automation, reducing waste collection operations' human labor.

Finally, integrating smart technologies in solid waste collection systems presents a promising approach to reducing occupational risks and improving operational efficiency. While challenges exist, particularly in developing regions, the long-term benefits in terms of worker safety, environmental sustainability, and automation outweigh the initial implementation costs. Future studies should focus on optimizing these technologies to ensure broader accessibility and effectiveness.

Conclusions

SWC remains a high-risk occupation, particularly in countries, where door-to-door collection systems expose workers to multiple occupational risks. These include ergonomic risks due to repetitive tasks, heavy lifting, awkward postures, and psychosocial and environmental hazards stemming from prolonged exposure to contaminated waste and harmful gases. The findings of this study highlight the urgent need for innovative solutions to reduce these risks and improve working conditions for waste collection workers.

The implementation of IoT-based waste management technologies presents a promising approach to mitigating occupational hazards, especially ergonomics risk, predominant in the door-to-door SWC system. Smart bins equipped with fill-level sensors, weight measurement systems, and real-time communication capabilities help optimize collection routes, reducing physical strain and minimizing direct human contact with waste. Additionally, the automation of waste sorting and gas concentration monitoring contributes to both worker safety and environmental sustainability.

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References

Abba, S., & Light, C. I. (2020). IoT-Based Framework for Smart Waste Monitoring and Control System: A Case Study for Smart Cities †. *Engineering Proceedings*, *2*(1). Scopus. https://doi.org/10.3390/ecsa-7-08224

Abidin, A. R., Irawan, Y., & Devis, Y. (2022). SMART TRASH BIN FOR MANAGEMENT OF GARBAGE PROBLEM IN SOCIETY. *Journal of Applied Engineering and Technological Science*, *4*(1), 202–208. Scopus. https://doi.org/10.37385/jaets.v4i1.1015

Abuga, D., & Raghava, N. (2021). Real-time smart garbage bin mechanism for solid waste management in smart cities. *SUSTAINABLE CITIES AND SOCIETY*, *75*. https://doi.org/10.1016/j.scs.2021.103347

Addas, A., Khan, M. N., & Naseer, F. (2024). Waste management 2.0 leveraging internet of things for an efficient and eco-friendly smart city solution. *PLoS ONE*, *19*(7 July). Scopus. https://doi.org/10.1371/journal.pone.0307608

AI Chat for scientific PDFs | SciSpace. (n.d.). Retrieved January 27, 2025, from https://typeset.io

Al Duhayyim, M., Mohamed, H., Aljebreen, M., Nour, M., Mohamed, A., Abdelmageed, A., Yaseen, I., & Mohammed, G. (2022). Artificial Ecosystem-Based Optimization with an Improved Deep Learning Model for IoT-Assisted Sustainable Waste Management. *SUSTAINABILITY*, *14*(18). https://doi.org/10.3390/su141811704

Bhowmik, A., Saef Ullah Miah, Md., & Mohaimen-Bin-Noor. (2020). IoT (Internet of Things)—Based smart garbage management system: A proposal for major cities of Bangladesh. *AIUB Journal of Science and Engineering*, *19*(1), 33–40. Scopus.

Decent Work in Waste Management:A Baseline Study on the Ward Contractor System in the City of Windhoek | International Labour Organization. (2014, May 13). https://www.ilo.org/publications/decent-work-waste-managementa-baseline-study-ward-contractor-system-city

Degli Esposti, A., Magrini, C., & Bonoli, A. (2023). Door-to-door waste collection: A framework for the socio—Economic evaluation and ergonomics optimisation. *Waste Management (New York, N.Y.)*, *156*, 130–138. https://doi.org/10.1016/j.wasman.2022.11.024

Door-to-Door Waste Collection › Evreka. (2022, May 23). https://evreka.co/use-cases/door-to-door-collection/

Dos Santos, N. D., Zlatar, T., Da Cruz, F. M., Barkokébas Junior, B., & Lago, E. M. G. (2020). Reduction of work accidents through the implementation of containers for solid waste collection. *International Journal of Occupational and Environmental Safety*, *4*(1), 62–72. https://doi.org/10.24840/2184-0954_004.001_0005

Elsayed Farid Amr, A., & Abdel Malek Hussein, A. (2021). Occupational Health Hazards and the Use of Safety Protective Measures among Municipal Solid Waste Collectors. *Egyptian Journal of Health Care*, *12*(2), 830–853. https://doi.org/10.21608/ejhc.2021.172053

Fayomi, G. U., Mini, S. E., Chisom, C. M., Fayomi, O. S. I., Udoye, N. E., Agboola, O., & Oomole, D. (2021). Smart Waste Management for Smart City: Impact on Industrialization. *IOP Conference Series: Earth and Environmental Science*, *655*(1), 012040. https://doi.org/10.1088/1755-1315/655/1/012040

Gutierrez, J. M., Jensen, M., Henius, M., & Riaz, T. (2015). Smart Waste Collection System Based on Location Intelligence. *Procedia Computer Science*, *61*, 120–127. https://doi.org/10.1016/j.procs.2015.09.170

Hossain, S., Hossain, M. F., Liu, B., Ara, A., Alsaoud, H., & Patwary, M. A. M. (2024). Health Challenges Among Waste Collectors in Bangladesh: Exploring Risk Factors Using Multi-level Modeling. *Safety and Health at Work*, S2093791124000799. https://doi.org/10.1016/j.shaw.2024.10.007

Hussain, A., Draz, U., Ali, T., Tariq, S., Irfan, M., Glowacz, A., Daviu, J. A. A., Yasin, S., & Rahman, S. (2020). Waste management and prediction of air pollutants using IoT and machine learning approach. *Energies*, *13*(15). Scopus. https://doi.org/10.3390/en13153930

Hussain, I., Elomri, A., Kerbache, L., & El Omri, A. (2024). Smart city solutions: Comparative analysis of waste management models in IoT-enabled environments using multiagent simulation. *SUSTAINABLE CITIES AND SOCIETY*,*103*. https://doi.org/10.1016/j.scs.2024.105247

I. Shah, A. A., M. Fauzi, S. S., J. M. Gining, R. A., R. Razak, T., F. Jamaluddin, M. N., & Maskat, R. (2021). A review of IoT-based smart waste level monitoring system for smart cities. *Indonesian Journal of Electrical Engineering and Computer Science*, *21*(1), 450. https://doi.org/10.11591/ijeecs.v21.i1.pp450-456

Jasim, A. M., Qasim, H. H., Jasem, E. H., & Saihood, R. H. (2021). An internet of things based smart waste system. *International Journal of Electrical and Computer Engineering (IJECE)*, *11*(3), 2577. https://doi.org/10.11591/ijece.v11i3.pp2577-2585

Joshi, L., Bharti, R., Singh, R., & Malik, P. (2022). Real time monitoring of solid waste with customized hardware and Internet of Things. *COMPUTERS & ELECTRICAL ENGINEERING*, *102*. https://doi.org/10.1016/j.compeleceng.2022.108262

Kaphle, M., Shai, S., Thapa, A., & Karki, R. (2024). Occupational health problems among waste collectors in a metropolitan city: A cross-sectional study: Article. *International Journal of Occupational and Environmental Safety*, *8*(2), 41–52. https://doi.org/10.24840/2184-0954-008.002-002482

Kasa, Silpa. (n.d.). *What a waste 2.0*. A Global Snapshot of Solid Waste Management to 2050. Retrieved January 7, 2025, from https://openknowledge.worldbank.org/entities/publication/d3f9d45e-115f-559b-b14f-28552410e90a

Lama, R., & Karmakar, S. (2024). Secure waste collection approach for smart cities. *International Journal of Information Technology (Singapore)*, *16*(4), 2439–2454. Scopus. https://doi.org/10.1007/s41870-024-01751-y

Maalouf, A., & Agamuthu, P. (2023). Waste management evolution in the last five decades in developing countries – A review. *Waste Management & Research: The Journal for a Sustainable Circular Economy*, *41*(9), 1420–1434. https://doi.org/10.1177/0734242X231160099

Mookkaiah, S. S., Thangavelu, G., Hebbar, R., Haldar, N., & Singh, H. (2022). Design and development of smart Internet of Things–based solid waste management system using computer vision. *Environmental Science and Pollution Research*, *29*(43), 64871–64885. https://doi.org/10.1007/s11356-022-20428-2

Okubanjo, A., Odufuwa, B., Okandeji, A., & Daniel, E. (2024). Smart Bin and IoT: A Sustainable Future for Waste Management System in Nigeria. *GAZI UNIVERSITY JOURNAL OF SCIENCE*, *37*(1), 222–235. https://doi.org/10.35378/gujs.1254271

Page, M. J., Moher, D., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … McKenzie, J. E. (2021). PRISMA 2020 explanation and elaboration: Updated guidance and exemplars for reporting systematic reviews. *BMJ*, n160. https://doi.org/10.1136/bmj.n160

Rajendren, M. P., Ramu, M., Rajendren, M. P., & Ramu, M. (2024). *Overview on Municipal Solid Waste*. IntechOpen. https://doi.org/10.5772/intechopen.1006901

Ramson, S., Moni, D., Vishnu, S., Anagnostopoulos, T., Kirubaraj, A., & Fan, X. (2021). An IoT-based bin level monitoring system for solid waste management. *JOURNAL OF MATERIAL CYCLES AND WASTE MANAGEMENT*, *23*(2), 516–525. https://doi.org/10.1007/s10163-020-01137-9

Rayyan | Home. (n.d.). Retrieved January 27, 2025, from https://new.rayyan.ai/

Rossi, M., Papetti, A., & Germani, M. (2022). A comparison of different waste collection methods: Environmental impacts and occupational risks. *Journal of Cleaner Production*, *368*. Scopus. https://doi.org/10.1016/j.jclepro.2022.133145 Sangkham, S., Thongtip, S., & Sakunkoo, P. (2021). Occupational health hazard exposure and health problems among solid waste collectors in phayao province, northern thailand. *Journal of Public Health and Development*, *19*(2), 206–218. Scopus.

Sung, W., Devi, I., Hsiao, S., & Fadillah, F. (2022). Smart Garbage Bin Based on AIoT. *INTELLIGENT AUTOMATION AND SOFT COMPUTING*, *32*(3), 1387–1401. https://doi.org/10.32604/iasc.2022.022828

Thakur, P., Ganguly, R., & Dhulia, A. (2018). Occupational Health Hazard Exposure among municipal solid waste workers in Himachal Pradesh, India. *Waste Management*, *78*, 483–489. https://doi.org/10.1016/j.wasman.2018.06.020

Van Nguyen, B., Tran, T. T. T., Hoang, N. T., Nguyen, B. N., & Nguyen, Q. T. (2020). Musculoskeletal pain and work-related risk factors among waste collectors in Hanoi, Vietnam: A cross-sectional study. *Open Access Macedonian Journal of Medical Sciences*, *8*(E), 498–508. Scopus. https://doi.org/10.3889/oamjms.2020.4866

Vishnu, S., Ramson, S., Senith, S., Anagnostopoulos, T., Abu-Mahfouz, A., Fan, X., Srinivasan, S., & Kirubaraj, A. (2021). IoT-Enabled Solid Waste Management in Smart Cities. *SMART CITIES*, *4*(3), 1004–1017. https://doi.org/10.3390/smartcities4030053

World Health Organization. (n.d.). *Health, safety and dignity of sanitation workers: An initial assessment: World Bank; 2019—Google Search*. Retrieved March 18, 2025, from https://cdn.who.int/media/docs/default-source/wash-documents/health-safety-dignity-of-sanitation-workers.pdf?sfvrsn=1eee5a94_10&download=true

Zhang, Q., Li, H., Wan, X., Skitmore, M., & Sun, H. (2020). An intelligent waste removal system for smarter communities.
Sustainability (Switzerland), *12*(17). Scopus. https://doi.org/10.3390/SU12176829

Ziaei, M., Choobineh, A., Abdoli-Eramaki, M., Ghaem, H., & Jaberi, O. (2019). Psychological and physical job demands, decision latitude, and work-related social support among Iranian waste collectors. *Waste Management*, *95*, 377–387. https://doi.org/10.1016/j.wasman.2019.06.031

Zotero | Your personal research assistant. (n.d.). Retrieved January 27, 2025, from https://www.zotero.org/