



OPEN ACCESS

EDITED BY

Mariana Erasmus,
University of the Free State, South Africa

REVIEWED BY

Tom Okello,
University of the Free State Qwaqwa
Campus, South Africa
Sebastian Jaen,
University of Antioquia, Colombia

*CORRESPONDENCE

R. A. Rasi
✉ rasi.ra@vit.ac.in

RECEIVED 18 March 2026

REVISED 13 May 2026

ACCEPTED 21 May 2026

PUBLISHED 04 June 2026

CITATION

Kariveliparambil A, Rasi RA, Varghese N,
Babu J, Saravanan K, Mohan VK and
Ranganathan M (2026) Gendered
environmental injustice in informal
recycling systems: health vulnerability
among women waste pickers.
Front. Sustain. 7:1833366.
doi: 10.3389/frsus.2026.1833366

COPYRIGHT

© 2026 Kariveliparambil, Rasi, Varghese,
Babu, Saravanan, Mohan and
Ranganathan. This is an open-access
article distributed under the terms of the
[Creative Commons Attribution License
\(CC BY\)](https://creativecommons.org/licenses/by/4.0/). The use, distribution or
reproduction in other forums is
permitted, provided the original
author(s) and the copyright owner(s) are
credited and that the original publication
in this journal is cited, in accordance
with accepted academic practice. No
use, distribution or reproduction is
permitted which does not comply with
these terms.

Gendered environmental injustice in informal recycling systems: health vulnerability among women waste pickers

Ashifa Kariveliparambil¹, R. A. Rasi^{2*}, Neethu Varghese³,
Jobi Babu⁴, K. Saravanan⁵, Visakh K. Mohan⁶ and
Maharishi Ranganathan⁷

¹Department of Social Work, Faculty of Health Sciences, Istanbul Gelisim University, Istanbul, Türkiye,

²Department of Social Sciences, School of Social Sciences and Languages, Vellore Institute of

Technology, Vellore, India, ³Department of English, Bishop Chulaparambil Memorial College,

Kottayam, India, ⁴School of Social Work, Marian College Kuttikkanam Autonomous, Idukki, India,

⁵Department of Defence and Strategic Studies, Dr. M. G. R. Educational and Research Institute Deemed

to be University, Chennai, India, ⁶School of Social Work, Marian College Kuttikkanam Autonomous,

Idukki, India, ⁷School of Social Sciences and Languages, Vellore Institute of Technology, Chennai, India

Introduction: Informal waste pickers play a vital, yet often unrecognized, role in urban recycling systems, contributing significantly to waste recovery and environmental sustainability. Although women waste pickers perform critical environmental functions, they face various occupational and social vulnerabilities. Women waste pickers in the informal recycling sector experience various health vulnerabilities shaped by occupational exposure, social exclusion, and limited access to welfare support. This study advances existing research by providing an integrated empirical analysis of the occupational, social, and institutional determinants of health vulnerability among women waste pickers.

Methods: A cross-sectional survey was conducted among 427 women waste pickers engaged in informal recycling activities in Tamil Nadu, India. Data on occupational exposure, social exclusion, social welfare support, and perceived health vulnerability were collected using structured questionnaires. Descriptive statistics were used to characterize the sample. Ordinal logistic regression was performed to examine the levels of health vulnerability and identify associated factors.

Results: The findings revealed that occupational exposure was significantly associated with a greater likelihood of experiencing higher health vulnerability. Women who reported more contact with hazardous waste were significantly associated, indicating that social marginalization and limited access to social resources are linked to higher reported health risks among waste pickers. In contrast, welfare support was associated with lower levels of severe health vulnerability. The findings suggest that health outcomes are associated with interconnected environmental, social, and institutional conditions in informal waste economies.

Discussion: This study underscores the gendered nature of environmental injustice in informal recycling systems. Addressing the health vulnerability of women waste pickers requires integrated policy interventions that combine measures for occupational safety, social protection programs, and inclusive waste governance that promote worker wellbeing and sustainable urban waste management.

KEYWORDS

environmental injustice, informal recycling, occupational exposure, social exclusion, sustainability, women waste pickers

1 Introduction

Rapid urbanization has intensified the challenge of managing municipal solid waste in cities worldwide (Goh et al., 2025; Sesay and Fang, 2025). Population growth and changing consumption patterns have increased urban waste generation (Sharholly et al., 2007; Addas et al., 2024). This growing waste stream places significant pressure on municipal authorities, particularly in developing countries with limited infrastructure and institutional capacity (Zhang et al., 2024; Rengerla and Angamuthu, 2025). In this context, informal recycling has emerged as a critical, yet often neglected, component of urban waste management.

Informal waste pickers play a central role in these systems by collecting, sorting, and selling recyclable materials from municipal waste. They contribute to resource recovery, which would otherwise be lost in landfills (Vivan, 2025). Materials such as plastics, metals, glass, and paper are reintroduced into local recycling markets through labor (Wilson et al., 2005; Alpha et al., 2025). These activities enhance recycling efficiency and reduce environmental burden. Consequently, informal recycling labor is increasingly recognized as an indispensable component of urban sustainability and circular economy initiatives (Tucker and Anantharaman, 2020; Korsunova et al., 2022).

Although waste pickers significantly contribute to environmental sustainability, their working conditions are precarious. Informal waste collection typically occurs in environments characterized by mixed municipal waste, unsanitary conditions, and limited occupational safety measures. Workers often handle contaminated materials without adequate protective gear, exposing themselves to significant health risks (Baral, 2018; Gutberlet, 2023). Exposure to hazardous waste, sharp objects, and airborne contaminants can cause injuries, infections, chronic pulmonary disease, and other ailments (Cruvinel et al., 2019). Limited institutional protections and restricted access to health services further exacerbate these risks (Tshivhase et al., 2022).

In addition to these physical hazards, waste pickers often experience social marginalization in urban communities. Waste work is often stigmatized because of its association with dirt and contamination issues. Consequently, people involved in informal waste collection may experience discrimination, verbal abuse, and social exclusion in public places (Aparcana, 2016; Coletto et al., 2017; Kain et al., 2022). These experiences undermine their social standing and limit their access to support networks and institutional resources.

Gender dynamics further complicate these patterns of vulnerability. In many urban contexts, women constitute a significant portion of the informal recycling workforce (Ogando et al., 2017). Female waste pickers often experience intersecting disadvantages linked to gender inequality, occupational hazards, and social stigma (Misra and Baheti, 2023). They may also face discrimination, harassment, and restricted economic opportunities (Wittmer, 2020; Chan et al., 2025). These overlapping conditions indicate that health risks are shaped by both occupational exposure and gendered social inequalities. These intersecting vulnerabilities highlight the importance of examining informal recycling systems from a gender-sensitive analytical perspective.

Although previous research has examined several aspects of informal waste work, important gaps remain. Studies have documented occupational health risks, such as respiratory illnesses, infections, and work-related injuries (Cruvinel et al., 2019; Ncube et al., 2016; Lissah et al., 2022; Joseph et al., 2026). Others have examined social marginalization and economic vulnerability (Zolnikov et al., 2021; Maneen et al., 2025). Sustainability research has also highlighted the environmental contributions of informal recycling (Vivan, 2025; Alpha et al., 2025). However, these dimensions are often examined in isolation, with limited empirical attention to how occupational exposure, social marginalization, and welfare access interact to shape health outcomes. Existing studies rarely integrate these dimensions into a unified analytical framework (Flynn et al., 2021; Tucker and Anantharaman, 2020; Binion and Gutberlet, 2012).

This gap is particularly significant for women engaged in informal recycling activities. Despite their substantial participation in waste picking, relatively few empirical studies have examined how gendered labor conditions intersect with environmental risks and social inequalities to influence health vulnerability (Ogando et al., 2017; Chan et al., 2025; Gutberlet and Uddin, 2017; Shanmugasundaram, 2024). Addressing this gap, the present study examines how occupational exposure, social exclusion, and welfare deficits are associated with health vulnerability among women waste pickers in the urban informal recycling system. By adopting an integrated analytical approach, the study moves beyond fragmented perspectives and provides a more comprehensive understanding of environmental injustice within informal waste economies. The findings contribute to ongoing debates on sustainable waste management by highlighting the gendered and socially embedded nature of informal recycling labor. These insights underscore the need for waste governance frameworks that recognize and address the labor conditions of informal waste workers, thereby promoting socially inclusive and environmentally sustainable systems.

2 Review of literature

2.1 Informal recycling systems and urban sustainability

Rapid urbanization has intensified the complexity of municipal waste management across many developing and emerging economies (Velis, 2017; Gutberlet, 2018; Hossain and Haque, 2026). As cities expand and consumption patterns change, the volume of municipal solid waste generated in urban areas continues to increase (Izquierdo-Horna and Camacho-Castañeda, 2022). In many circumstances, formal waste management systems are unable to cope with this growing waste stream (Addas et al., 2024; Zhang et al., 2024; Medina, 2010). Informal recycling systems have filled this institutional gap and have become an important part of urban waste recovery.

Waste pickers function at the core of these systems. By collecting, sorting, and selling recyclable materials from municipal waste streams, they play an important role in diverting waste from landfills and

supporting material recovery processes (Gutberlet and Uddin, 2017; Dias, 2016; Wibin and Kalina, 2025). Empirical research indicates that informal recyclers improve recycling efficiency in many cities. Studies across Asia, Africa, and Latin America have shown that informal waste pickers recover substantial quantities of recyclable materials that are often missed by formal municipal systems (Alpha et al., 2025; Wilson et al., 2008; Gutberlet, 2009).

Circular economy discussions increasingly acknowledge the contributions of informal waste workers to sustainability issues. Informal recycling effectively extends the life of materials and reduces the pressure on natural resource extraction (Korsunova et al., 2022; Wilson et al., 2008). Various studies have shown that waste pickers can reduce municipal waste management costs by performing labor-intensive recycling functions that are not feasible at scale by municipal authorities (Alpha et al., 2025; Fergutz et al., 2011; Addas et al., 2024).

Despite these contributions, informal waste workers remain largely excluded from formal waste governance structures. Waste pickers usually lack labor protection, social security, or institutional recognition (Marello and Helwege, 2017; Neville et al., 2023). Their environmental contributions coexist with social marginalization and economic insecurity (Misra and Baheti, 2023; Barford et al., 2021). This contradiction highlights a key limitation in existing sustainability frameworks, where environmental gains are often achieved alongside persistent social inequalities. However, much of the existing literature emphasizes environmental and economic contributions while giving comparatively limited attention to the social and gendered dimensions of informal recycling labor. Accordingly, understanding the conditions under which informal recycling labor occurs is key to assessing the social sustainability of urban waste management systems.

2.2 Occupational health risks in informal waste work

Informal recycling provides environmental and economic benefits; however, it is also associated with serious occupational health risks (Maneen et al., 2025). According to Baral (2018) and Cruvinel et al. (2019), waste pickers work with mixed municipal waste, which contains organic waste, hazardous waste, medical waste, and sharp objects. Direct exposure to these substances poses risks of both immediate injuries and long-term adverse health outcomes.

Research on occupational health among waste workers has documented a wide range of health vulnerabilities. Respiratory diseases, skin conditions, musculoskeletal issues, and gastrointestinal diseases have been reported among those engaged in waste collection and recycling (Zolnikov et al., 2021; Poonkasem et al., 2022). Continuous exposure to decomposing organic waste and airborne pollutants may lead to chronic respiratory conditions, and frequent contact with contaminated materials increases the risk of infectious diseases (Vimercati et al., 2016).

Injuries from sharp objects pose another major hazard in informal waste work. According to Magalhães et al. (2021) and Cook et al. (2022), broken glass, metal pieces, and medical waste are common in municipal refuse. Waste pickers without sufficient protective equipment are at an increased risk of cuts, puncture wounds, and infections. Musculoskeletal strain is common, as waste collection work is physically demanding and often requires lifting heavy loads and transporting recyclable materials over long distances (Poonkasem et al., 2022; Uhumamure et al., 2021).

A major reason for these health hazards is the scarcity of personal protective equipment (PPE). Informal waste workers rarely have access to gloves, masks, and protective footwear. In addition, many waste pickers lack access to occupational health services or preventive healthcare programs (Shanmugasundaram, 2024; Kistan et al., 2020). Consequently, health issues related to waste work may not receive treatment or may only worsen.

While these studies provide important evidence on occupational health risks, they are predominantly based on cross-sectional and descriptive approaches, which limit the understanding of how these risks interact with broader social and institutional factors. Although waste pickers help the environment with their work, formal urban waste management policies mostly overlook the health hazards to which they are exposed (Schenck et al., 2019).

2.3 Gendered vulnerabilities in informal waste work

Gender plays a significant role in shaping the labor experiences within informal recycling systems. In many cities, a large number of women are part of the informal waste workforce. Nonetheless, their participation often occurs under conditions of economic insecurity, social marginalization, and limited institutional protection (Ogando et al., 2017; UNEP, 2016; Sibanda and Erwin, 2023).

Studies on gender and informal labor show that women's participation in the informal economy is concentrated in precarious segments. Women waste pickers often receive lower incomes, have limited bargaining power within recycling markets, and face greater barriers to accessing social protection programs (Misra and Tewari, 2022; Fredman, 2023). These structural inequalities reflect broader patterns of gendered labor segmentation in informal economic systems.

Women involved in waste picking may also face intensified occupational risk. In addition to the physical hazards associated with waste collection, female waste workers may encounter harassment, discrimination, and gender-based violence in public spaces (Chan et al., 2025; Barford et al., 2021). Certain studies have shown that women waste pickers suffer social stigma, exclusion, and verbal abuse in informal recycling communities (Wittmer, 2020; Mlotshwa et al., 2022).

Gendered responsibilities within households may further compound these vulnerabilities. Many women waste pickers simultaneously perform unpaid domestic labor alongside income-generating waste work. The cumulative impact of workplace stressors and household responsibilities tends to aggravate physical fatigue and restrict access to healthcare (Barford et al., 2021).

Although previous studies have documented gendered inequalities, they often examine occupational risks and social vulnerabilities in isolation, with limited empirical attention to how these factors intersect to shape health outcomes. This limitation highlights the need for an integrated, gender-sensitive analysis of environmental injustice in informal recycling systems.

2.4 Social exclusion and stigma in waste work

Urban waste pickers often occupy a socially marginal position. Waste work is frequently associated with stigma because of its perceived connection to dirt, contamination, and low social status (Coletto and Carbonai, 2023; Sharma, 2023). These perceptions can

contribute to discriminatory treatment, social exclusion, and limited opportunities for economic mobility.

Several studies have documented waste pickers experiences of verbal abuse, harassment, and negative public attitudes while collecting recyclable materials in public spaces (Parra, 2020; Morais et al., 2022; Kadyamadare and Samson, 2023). Such stigma can reinforce the invisibility of waste workers within urban societies and reduce their ability to claim labor rights or social recognition.

Social exclusion may also influence access to public services and institutional resources. Individuals working in informal recycling systems often lack formal employment status, which can limit their eligibility for social welfare programs, healthcare benefits, or occupational safety protections (Marello and Helwege, 2017; Das, 2025; Gutberlet and de Vallin, 2025). Existing research indicates that waste pickers are frequently excluded from formal governance frameworks that regulate labor and environmental standards (Barford et al., 2021; Gomes and Neto, 2018). While these studies highlight important dimensions of social exclusion, they often adopt descriptive approaches with limited attention to how stigma and institutional exclusion interact with occupational risks to influence health outcomes. Consequently, addressing the sustainability of urban waste management requires consideration of both environmental outcomes and the social conditions under which waste workers live and work.

2.5 Environmental justice and sustainability inequalities

The environmental justice framework provides an essential lens to understand inequalities within environmental governance systems (Gandy, 2013). Environmental justice research shows that the distribution of environmental risks and benefits is uneven (Das, 2025; Mohai et al., 2009). Marginalized communities are often more exposed to environmental hazards and derive fewer benefits from environmental resources and services (Masuda and Crabtree, 2010; Kaufman and Hajat, 2021). Within informal recycling systems, waste pickers represent a population that embodies this imbalance. Their work contributes to environmental sustainability through resource recovery and waste diversion; however, they remain exposed to hazardous working conditions and limited institutional protections (Chan et al., 2025). This dynamic illustrates a form of environmental injustice in which socially marginalized workers disproportionately bear the environmental burdens associated with waste management (Shanmugasundaram, 2024). However, much of the existing literature uses environmental justice as a descriptive framework, with limited

empirical integration of occupational, social, and institutional dimensions to explain health outcomes.

Recent sustainability research has highlighted the importance of incorporating social justice into environmental policies. Urban sustainability initiatives increasingly emphasize waste reduction and circular economy strategies; however, they often overlook the labor conditions of informal waste workers (Kotsila et al., 2022; Hadfield et al., 2025; da Cruz et al., 2025). Without addressing these inequalities, sustainability policies risk reinforcing the existing patterns of social marginalization. Recognizing the environmental and social contributions of informal waste workers is essential for developing inclusive sustainability frameworks that integrate occupational safety, social protection, and equitable waste governance.

3 Conceptual framework and hypothesis development

This study draws on the literature reviewed above to conceptualize the experiences of women waste pickers through an environmental justice lens, linking occupational exposure, social exclusion, and welfare deficits to health vulnerability. Women waste pickers are often exposed to hazardous waste, unsanitary conditions, and poorly managed protective equipment (Chan et al., 2025). Occupational exposure threatens the physical health and safety of workers.

Simultaneously, waste pickers often experience social exclusion arising from occupational stigma and discrimination. Social marginalization may reduce access to social support networks and institutional services that could otherwise mitigate health risks (Maneen et al., 2025). Institutional factors further shape these outcomes. In many urban contexts, informal waste workers lack access to welfare programs, occupational safety training, and healthcare support mechanisms (Zolnikov et al., 2021). The absence of institutional protection contributes to the persistence of vulnerability among waste workers.

Taken together, these dynamics suggest that the interaction of occupational hazards, social exclusion, and institutional welfare gaps shapes health outcomes among women waste pickers. Therefore, the conceptual framework proposed in this study examines how these factors jointly influence health vulnerability in the informal recycling system. Figure 1 presents the conceptual model that guided this study.

Drawing on the conceptual framework and existing empirical research on informal waste work, occupational health, and environmental justice, this study examines the factors that influence health vulnerability among women engaged in informal recycling. Previous

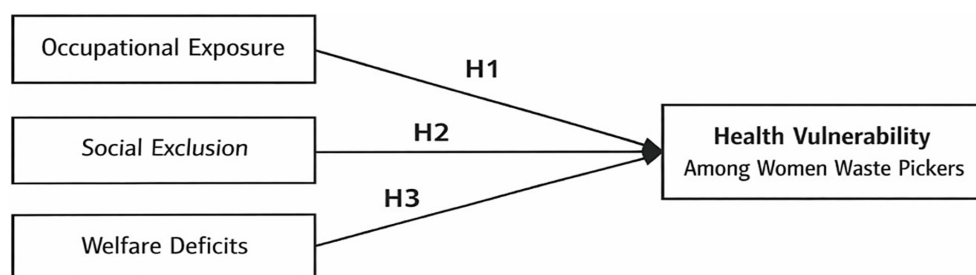


FIGURE 1
Conceptual model of the study.

studies have indicated that waste pickers frequently operate in hazardous environments, where exposure to contaminated materials, sharp objects, and unsanitary conditions significantly increases the risk of occupational injuries and illnesses (Cruvinel et al., 2019; Rani et al., 2023). These conditions highlight the critical role of occupational exposure in shaping health risks within informal recycling systems (Magalhães et al., 2021; Anshur et al., 2024). Accordingly, occupational exposure is expected to play a significant role in shaping health outcomes among waste workers.

In addition to occupational risks, social marginalization may intensify vulnerability. Waste pickers often encounter stigma, discrimination, and exclusion in public and community spaces due to the perceived social status associated with waste work. These forms of marginalization can restrict access to social support networks, healthcare services, and other institutional resources essential for health protection. Consequently, social exclusion may contribute to adverse health outcomes among women engaged in informal waste collection (Wittmer, 2020; Chan et al., 2025).

Institutional factors also influence the wellbeing of informal workers. In many urban contexts, waste pickers operate outside formal labor protection systems and have limited access to welfare programs, occupational safety training, or healthcare support (Mareello and Helwege, 2017). Such institutional gaps may further intensify existing occupational risks and reinforce structural health vulnerabilities among women waste pickers. This study applies the environmental justice framework not only as a descriptive perspective but also as an analytical lens to examine how environmental burdens (occupational exposure), social marginalization (social exclusion), and institutional disparities (welfare access) are unevenly distributed and collectively associated with health vulnerability among women waste pickers.

Based on these considerations, this study proposes the following hypothesis:

H1: Higher levels of occupational exposure increase the likelihood of health vulnerability among women waste pickers.

H2: Greater experience of social exclusion is associated with increased health vulnerability among women waste pickers.

H3: Limited access to institutional welfare support increases health vulnerability among women waste pickers.

4 Materials and methods

4.1 Research design and study setting

This study adopted a cross-sectional quantitative research design to examine the determinants of health vulnerability among women engaged in informal waste picking. The analysis focuses on three key dimensions—occupational exposure, social exclusion, and access to welfare support—in shaping health vulnerabilities. Cross-sectional survey approaches are widely used in occupational and environmental health research to examine the association between working conditions and health risks among marginalized labor groups.

This empirical investigation was conducted in selected municipal areas in Tamil Nadu, India, where informal waste picking is an important component of local recycling systems. In many Indian cities,

informal waste pickers play a significant role in material recovery and recycling, but are not covered by formal labor protections. The chosen municipality represents a typical urban context in which informal waste workers operate with limited occupational protection and institutional support.

4.2 Sampling and data collection

The target population comprised women engaged in informal waste-picking in the selected municipal areas. Participants were identified through field visits to locations where waste pickers typically work, including municipal dumping grounds, waste aggregation sites, and informal recycling areas in selected municipal locations in the Virudhunagar district, Tamil Nadu, such as Rajapalayam and Srivilliputhur. A non-probability purposive sampling strategy was employed to recruit participants who were actively involved in waste collection, sorting, or recycling. This approach is appropriate for studying hard-to-reach populations lacking a formal sampling frame; however, it may limit the generalizability of the findings beyond the study context.

A structured questionnaire was administered via interviews. As most respondents were not formally educated, the questionnaire was administered in an interviewer-assisted format to help them understand the questions and record their responses accurately. Interviews conducted in the local language allowed the participants to describe their working conditions and health experiences comfortably. Respondents were informed of the study, provided informed consent, and participation was entirely voluntary.

A total of 427 female waste pickers participated in the survey. This sample size provides sufficient statistical power for multivariate analysis and enables a robust examination of the relationships between occupational exposure, social exclusion, welfare support, and health vulnerability outcomes. Completed questionnaires were reviewed during data collection to ensure completeness and consistency prior to inclusion in the analytical dataset.

4.3 Survey instrument and measurement of variables

The survey instrument was designed based on indicators widely used in previous research examining occupational hazards, health risks, and social marginalization among waste workers. The existing literature on waste management, occupational health, and informal labor provides a conceptual basis for identifying relevant indicators associated with exposure conditions, social exclusion, and work-related health outcomes. The full survey instrument used for data collection is provided in [Appendix](#) to ensure the study's transparency and replicability. [Table 1](#) presents the indicators used to construct the indices and the supporting literature from which these measures were derived.

The Health Vulnerability Index was the dependent variable in the analysis. This index captures the extent to which respondents reported experiencing health problems that are commonly associated with waste-picking activities. Four indicators were used to construct the index: respiratory problems related to waste exposure, dermatological conditions, musculoskeletal pain associated with physically demanding work, and work-related injuries, such as cuts or infections. Each indicator was recorded as a binary response (0 = no, 1 = yes), and the index was calculated by summing the indicators. Consequently, the

TABLE 1 Indicators used to construct the study indices and their supporting literature sources.

Index	Indicator
Occupational Exposure Index	Exposure to biomedical or hazardous waste materials (Zolnikov et al., 2021; Binion and Gutberlet, 2012)
	Exposure to sharp waste materials (needles, broken glass, metal scraps; Binion and Gutberlet, 2012; Medina, 2010)
	Exposure to smoke from burning waste (Zolnikov et al., 2021; Baral, 2018)
	Lack of protective gloves during waste handling (Zolnikov et al., 2021; Medina, 2010)
	Lack of protective masks or respiratory protection (Medina, 2010; Dias, 2016)
	Direct contact with mixed municipal waste without safety equipment (Zolnikov et al., 2021; Dias, 2016)
Social Exclusion Index	Experience of discrimination due to waste-picking occupation (Dias, 2016; Wittmer, 2020)
	Verbal abuse or stigmatization in public spaces (Wittmer, 2020; Kain et al., 2022)
	Physical harassment during waste-picking activities (Dias, 2016; Wittmer, 2020; Gutberlet and Carenzo, 2020)
Health Vulnerability Index	Respiratory problems associated with waste exposure (Zolnikov et al., 2021; Cruvinel et al., 2019)
	Skin disease or dermatological infection (Zolnikov et al., 2021; Made et al., 2020)
	Musculoskeletal pain related to heavy lifting or prolonged work (Medina, 2010; Gutberlet and Uddin, 2017)
	Work-related injuries (cuts, infections, accidents; Zolnikov et al., 2021; Yang et al., 2017)

The indicators listed above were used to construct composite indices measuring occupational exposure, social exclusion, and health vulnerability among women waste pickers. Each indicator was derived from established measures reported in previous research on informal waste work, occupational health risks, and social marginalization in waste-picking communities.

index ranges from 0 to 4, with higher scores indicating greater health vulnerability.

The Occupational Exposure Index measures the extent of hazardous working conditions encountered by respondents while engaged in waste-picking activities. The index was constructed by summing six binary indicators representing key exposure risks identified in the literature on informal waste work. These include exposure to biomedical waste, exposure to chemical waste, contact with sharp objects such as broken glass or needles, exposure to smoke from burning waste, the absence of protective gloves, and the absence of protective masks or respiratory protection. Each indicator was coded as 0 (no) or 1 (yes), and the resulting index ranges from 0 to 6. Higher scores indicate greater occupational exposure to hazardous waste conditions.

The Social Exclusion Index captures the experiences of stigma and discrimination associated with informal waste picking occupations. Three indicators were used to construct the index: experience of discrimination due to involvement in waste picking, verbal abuse or stigmatization in public spaces, and physical harassment encountered during waste collection activities. These indicators were measured as binary responses (0 = no, 1 = yes) and summed to produce an index ranging from 0 to 3, with higher scores indicating greater levels of social exclusion experienced by respondents.

In addition to these indices, the study included a welfare support score that reflects respondents' reported access to welfare assistance or institutional support services. Participants indicated the level of welfare or support available to them using an ordinal response scale ranging from 1 to 4, with higher values representing greater access to support mechanisms such as health assistance, municipal aid, or community-based services.

The indices employed in this study were constructed as composite (formative) measures derived from theoretically grounded indicators identified in prior literature. In contrast to reflective scales, in which items are expected to exhibit high internal consistency, the indicators included in each index capture distinct yet complementary dimensions of occupational exposure, social exclusion, and health

vulnerability. Accordingly, internal consistency measures, such as Cronbach's alpha, are not conceptually appropriate in this context, as the indicators are not expected to be highly correlated but instead collectively represent cumulative risk conditions. Instead, the validity of the indices is supported through their theoretical grounding, consistency with prior empirical studies, and the relevance of selected indicators to the lived conditions of informal waste workers. In addition, the robustness of the indices was assessed by examining the consistency of regression results across alternative model specifications, confirming that the direction and significance of key relationships remained stable. This approach is consistent with practices in occupational and public health research, where cumulative risk and vulnerability indices are widely used to capture multidimensional constructs.

The analysis included several control variables representing key sociodemographic characteristics that may influence health vulnerabilities. These included age, highest level of educational attainment, monthly income, and years of work experience in waste picking. Education was measured as a binary variable, indicating whether respondents had received formal schooling. Age and work experience were measured in terms of years. Income was obtained as the monthly total earnings reported by the respondents.

4.4 Mode of analysis

The analysis proceeded in several stages. First, descriptive statistics were calculated to characterize the study sample and examine the distribution of key study variables. This step provided an overview of the demographic conditions, occupational exposure patterns, and reported health outcomes among female waste pickers.

Second, prevalence analyses were conducted to investigate how often exposure conditions were encountered at work and the experiences of social exclusion and work-related health problems reported by the respondents. These analyses illustrate the types of risks commonly encountered by women engaged in informal waste picking.

Third, Pearson's correlation analysis was used to investigate the bivariate relationships between the study variables. Although some variables were constructed using binary indicators, Pearson's

correlation was appropriate in this context because the variables were operationalized as composite indices, and the sample size was sufficiently large to support robust estimation. This step provided a preliminary assessment of the association between occupational exposure, social exclusion, welfare support, and health vulnerability.

Variance inflation factor (VIF) statistics were calculated to assess multicollinearity among explanatory variables. The results indicate no evidence of problematic intercorrelations that could bias the regression estimates.

This study employed ordinal logistic regression as the main analysis model. This model is appropriate because the dependent variable, the Health Vulnerability Index, represents the ordered levels of health risk derived from multiple health indicators. The model estimates the effects of occupational exposure, social exclusion, and welfare support on the likelihood of experiencing high health vulnerability. Model diagnostics were conducted to evaluate the adequacy of the regression model, including likelihood ratio tests, pseudo- R^2 statistics, and the parallel lines test to assess the proportional odds assumption. The results indicate that the proportional odds assumption is satisfied. In addition, predicted probabilities were estimated to illustrate how the likelihood of experiencing different levels of health vulnerability varied with occupational exposure, holding other variables constant.

5 Results

This section presents the empirical findings of the study, which examines health vulnerability among women waste pickers engaged in informal recycling activities. The analysis proceeds in a structured sequence to provide a comprehensive understanding of the relationships between occupational risks, social exclusion, welfare support, and health vulnerability. First, descriptive statistics summarize the respondents' demographic and work characteristics. This is followed by an examination of occupational exposure conditions and experiences of social exclusion, both of which represent key structural determinants of vulnerability in informal waste work. The prevalence of major health conditions is then assessed to contextualize the health risks faced by the study population. Subsequently, the study examines bivariate correlations to assess associations between variables. Multicollinearity diagnostics are presented to verify whether the variables are suitable for regression modeling. Finally, an ordinal logistic regression model is estimated to evaluate the effects of occupational exposure, social exclusion, and welfare support on health vulnerability while controlling for demographic and work-related characteristics. Model diagnostics are reported to confirm the validity and adequacy of the regression model.

5.1 Socio-demographic and occupational characteristics of women waste pickers

Descriptive statistics were first examined to provide an overview of the demographic, socioeconomic, and occupational characteristics of the study participants. This step is essential for contextualizing the conditions under which women engage in informal waste-picking activities and for understanding the distribution of the key variables included in the analytical model. By summarizing the central tendencies and variability of these variables, the descriptive analysis offers an

initial picture of the structural environment that shapes occupational exposure, social exclusion, and health vulnerability.

Table 2 presents the descriptive statistics for the principal variables in this study. The findings reveal that most respondents are middle-aged workers aged 38.51 years ($SD = 10.86$) on average. This suggests that most women waste pickers were in their active working years, reflecting the physically demanding nature of informal recycling activities. Most respondents in the sample had a low level of education. The binary education variable ($M = 0.55$, $SD = 0.50$) indicates that just over half of the respondents had received some form of formal schooling, while a substantial proportion had no formal education at all. The respondents' economic situation reveals that informal waste work is precarious. The average monthly income was INR 5,611 ($SD = 1,149.52$), indicating relatively modest and unstable earnings in the informal recycling sector. Regarding work experience, respondents reported an average of 8.07 years ($SD = 4.35$) in waste picking; that is, many of the women had not quit this line of work for a long time despite its hazards.

The study also reveals substantial exposure to occupational risks. The mean value of the Occupational Exposure Index was 3.71 ($SD = 1.17$), indicating that female waste pickers were exposed to perils several times during their working hours. Most of them came into contact with hazardous waste, chemical materials, sharp objects, and smoke from burning waste without proper protective equipment. These levels of occupational exposure indicate sustained contact with hazardous conditions, which may contribute to increased health vulnerability among women waste pickers. According to the findings, the Social Exclusion Index also received a relatively high mean score (1.60, $SD = 0.85$), indicating that respondents faced stigma, discrimination, and harassment on most occasions in their occupations. In contrast, the Welfare Support Score showed a comparatively low mean value of 2.45 ($SD = 1.16$), suggesting limited access to institutional or community-based welfare mechanisms among female waste pickers.

The Health Vulnerability index, as the dependent variable, had a mean of 1.88 ($SD = 0.98$), indicating moderate levels of health vulnerability. The index reflects the co-occurrence of multiple health conditions, indicating that respondents' health risks are cumulative rather than isolated. Taken together, these descriptive findings portray a workforce characterized by modest incomes, prolonged involvement in informal waste-picking activities, frequent exposure to occupational hazards, and significant social marginalization. A conceptual background will help explain the following analyses of the health vulnerability of women waste pickers arising from occupational exposure, social exclusion, and welfare support.

5.2 Occupational exposure conditions among women waste pickers

Determining occupational exposure conditions forms the basis of structural health risk analysis among women engaged in informal waste-picking activities. Waste pickers frequently operate in environments characterized by hazardous materials, poor safety infrastructure, and limited access to protective equipment. Examining the occurrence of certain occupational hazards elucidates the types of exposure that may increase susceptibility to ill health in this population. This analysis focuses on identifying the most common

occupational risk conditions faced by women waste pickers during waste collection and sorting.

As shown in Table 3, the respondents reported the distribution of key occupational exposure conditions. The findings revealed that hazardous working conditions are prevalent among female waste pickers. A substantial proportion of respondents reported exposure to sharp objects, including needles, broken glass, and metal fragments; 69.3% of participants reported frequently encountering these risks during waste-picking activities. This type of risk is a serious occupational hazard, increasing the likelihood of injuries, infections, and other work-related illnesses.

Additionally, 65.1% of respondents reported being exposed to biomedical waste, revealing that numerous female waste pickers are in contact with infectious material. Exposure to chemical waste was also common, affecting 57.8% of the participants, further highlighting the hazardous nature of informal recycling environments, where waste segregation is often absent.

Of the respondents, 51.8% reported exposure to smoke or burning waste. Exposure to such environments can cause respiratory problems and other long-term health impacts, especially in places where waste is openly burned.

The results revealed that the study population also lacked protective equipment and was directly exposed to hazardous materials. Most respondents (72.4%) worked without gloves; however, an even higher proportion (78.2%) did not use masks while waste-picking. The lack of essential safety equipment can lead to injury, infection, long-term exposure to harmful substances, and other complications. The combined absence of protective equipment and frequent exposure to hazardous materials suggests a heightened risk of adverse health outcomes among women waste pickers.

The reported confidence intervals demonstrate that these prevalence estimates are precise for the samples. The findings indicate that women waste pickers are regularly exposed to several occupational hazards in their day-to-day work. These overlapping exposure conditions indicate that occupational risks are not isolated but cumulative, potentially intensifying health vulnerability over time. These findings underscore the structurally unsafe conditions associated with informal waste management systems and provide important context for understanding the occupational determinants of health vulnerability examined in subsequent studies.

5.3 Experiences of social exclusion among women waste pickers

Women engaged in informal waste picking encounter occupational risks and social marginalization. Waste pickers are often stigmatized, which can result in discrimination, social exclusion, and various forms of harassment in public spaces. Experiencing social and psychological distress can limit access to social support networks and public goods, creating broader health vulnerabilities. Therefore, it is important to examine the prevalence of experiences of social exclusion to understand the broader social context of health risks among female waste pickers. Table 4 presents the distribution of the key indicators of social exclusion reported by the respondents.

The findings reveal that experiences of social marginalization are widespread among women waste pickers. Most respondents (62.8%) reported experiencing discrimination because of their waste-picking occupation, indicating that the social stigma associated with this form of work remains pervasive. Such discrimination often manifests as negative attitudes, social distancing, or exclusion from the community.

In addition, 56.4% of respondents reported experiencing verbal abuse or stigmatization in public spaces while waste-picking. These experiences may include derogatory comments, humiliation, or other forms of verbal hostility directed at waste pickers because of the perceived social status of their work in the waste management sector.

A substantial proportion of participants also reported physical harassment during waste picking, affecting 41.2% of respondents. Although less prevalent than other forms of social exclusion, this finding highlights the vulnerability of women waste pickers to unsafe and hostile social environments during their daily work.

The confidence intervals for these estimates indicate a reasonable level of precision for the prevalence measures across the samples. Taken together, these findings demonstrate that women waste pickers not only face hazardous occupational conditions but also experience considerable levels of social stigma and harassment. Such social exclusion represents an additional layer of vulnerability that may exacerbate the health risks associated with participation in informal waste work.

TABLE 2 Descriptive statistics of study variables ($N = 427$).

Variable	Mean	SD	Min	Max
Age (years)	38.51	10.86	20	55
Education	0.55	0.50	0	1
Monthly Income (INR)	5,611	1149.52	3,500	9,213
Years of Work in Waste Picking	8.07	4.35	1	15
Occupational Exposure Index	3.71	1.17	1	6
Social Exclusion Index	1.60	0.85	0	3
Welfare Support Score	2.45	1.16	1	4
Health Vulnerability Index	1.88	0.98	0	4

Education was coded as a binary variable (0 = no formal schooling; 1 = formal education). The occupational exposure index was constructed by summing six binary indicators of hazardous working conditions experienced during waste-picking activities, including exposure to biomedical waste, chemical waste, sharp objects, smoke from burning waste, and the absence of protective gloves and masks. The social exclusion index was calculated by summing three binary indicators reflecting experiences of discrimination, verbal abuse or stigmatization, and physical harassment associated with waste-picking activities. The health vulnerability index was derived by summing four binary indicators of self-reported health conditions, namely respiratory problems, skin disease, musculoskeletal pain, and frequent work-related injuries. The welfare support score reflects the level of access to welfare or institutional support services reported by respondents, with higher scores indicating greater support.

TABLE 3 Distribution of occupational exposure conditions among women waste pickers (N = 427).

Occupational exposure indicator	Frequency (Yes)	Percentage (%)	Mean	SD	95% CI
Exposure to biomedical waste	278	65.1	0.65	0.48	0.61–0.70
Exposure to chemical waste	247	57.8	0.58	0.49	0.53–0.63
Exposure to sharp objects (needles, glass, metal)	296	69.3	0.69	0.46	0.65–0.73
Exposure to smoke or burning waste	221	51.8	0.52	0.50	0.47–0.57
Lack of protective gloves	309	72.4	0.72	0.45	0.68–0.76
Lack of protective masks	334	78.2	0.78	0.41	0.74–0.82

Values represent the prevalence of occupational hazards reported by women waste pickers during waste collection and sorting activities. The means represent the proportion of respondents exposed to each occupational risk condition. Confidence intervals (CI) indicate the precision of prevalence estimates.

5.4 Prevalence of health conditions among women waste pickers

Assessing the prevalence of health conditions among women waste pickers is critical for understanding the direct health implications of hazardous working environments and social marginalization within informal recycling systems. Waste pickers are exposed to contaminated materials for extended periods. They suffer from physical strain and work under unsafe conditions. All of this may cause occupational health problems. Consequently, analyzing the prevalence of common health conditions provides an important empirical basis for evaluating this community's level of health vulnerability.

Table 5 presents the prevalence of key self-reported health conditions among respondents. According to the research findings, women waste pickers face numerous health concerns. The most prevalent condition identified in the study was musculoskeletal pain, reported by 60.4% of respondents. This high prevalence likely reflects the physically demanding nature of waste-picking activities, which often involve repetitive movements, lifting heavy loads, prolonged bending, and extended periods of manual waste sorting.

A substantial proportion (50.1%) of the respondents reported experiencing respiratory problems. Exposure to dust, smoke from burning waste, and hazardous airborne particles during waste collection and sorting may contribute to respiratory irritation and chronic breathing difficulties among workers in informal recycling environments.

Moreover, 44.3% of the respondents reported having skin diseases or skin problems. Regular exposure to contaminated waste, chemicals, and unclean surroundings can cause skin infections, allergic reactions, and other skin-related complications.

The study further reveals that 33.3% of women waste pickers experienced frequent work-related injuries. These injuries can result from sharp objects such as broken glass, metal fragments, and needles, which are often present in mixed waste. The reported confidence intervals suggest a reasonable level of precision in the estimated prevalence rates.

5.5 Bivariate relationships among key study variables

Before estimating the multivariate regression model, a correlation analysis was conducted to examine the bivariate relationships

among the study's principal variables. This stage is relevant for two reasons. First, it provides an initial understanding of how occupational exposure, social exclusion, welfare support, and health vulnerability are related. Second, it helps identify the relationships between various explanatory variables and their regressions. Examining these preliminary relationships, therefore, offers a useful diagnostic perspective on the data's structure. Table 6 presents Pearson's correlation coefficients among the key study variables. Although several variables were constructed from binary indicators, Pearson's correlation is appropriate here, as the variables are operationalized as composite indices and the sample size is sufficiently large to ensure robust estimation.

The results indicate that occupational exposure is positively associated with health vulnerability ($r = 0.21, p < 0.01$), suggesting that greater exposure to hazardous working conditions is linked to increased health vulnerability among women waste pickers. This relationship is consistent with the expectation that frequent contact with hazardous materials and unsafe working environments may contribute to adverse health effects.

Similarly, social exclusion was positively correlated with health vulnerability ($r = 0.17, p < 0.01$). This finding indicates that women waste pickers who experience greater levels of discrimination, stigmatization, or harassment tend to report higher levels of health vulnerability. The results highlight the potential influence of social marginalization on health conditions in the context of informal labor.

In contrast, welfare support was negatively correlated with health vulnerability ($r = -0.14, p < 0.05$), suggesting that access to welfare-related resources and institutional support may help mitigate health risks among women waste pickers. This negative association indicates that higher welfare support is associated with lower health vulnerability.

The correlation matrix also revealed a modest positive relationship between occupational exposure and social exclusion ($r = 0.18, p < 0.01$), suggesting that individuals with greater occupational risk may be more likely to experience social marginalization. Additionally, years of work in waste picking were positively correlated with occupational exposure ($r = 0.26, p < 0.01$) and health vulnerability ($r = 0.18, p < 0.01$), suggesting that prolonged involvement in waste-picking activities may increase cumulative exposure to hazardous conditions and associated health risks.

Age was moderately correlated with years of work ($r = 0.41, p < 0.01$), as expected, given that longer occupational engagement generally corresponds to older age. Other correlations among the variables were relatively weak, indicating that the predictors did not exhibit strong interrelationships that could threaten the stability of subsequent regression analyses.

TABLE 4 Distribution of social exclusion experiences among women waste pickers ($N = 427$).

Social exclusion indicator	Frequency (Yes)	Percentage (%)	Mean	SD	95% CI
Experience of discrimination due to the waste-picking occupation	268	62.8	0.63	0.48	0.58–0.67
Verbal abuse or stigmatization in public spaces	241	56.4	0.56	0.50	0.52–0.61
Physical harassment during waste-picking activities	176	41.2	0.41	0.49	0.36–0.46

Values represent the prevalence of social exclusion experiences reported by women waste pickers. Means represent the proportion of respondents reporting each condition. Confidence intervals (CI) indicate the precision of the estimated prevalence rates.

TABLE 5 Prevalence of health conditions among women waste pickers ($N = 427$).

Health condition	Frequency (Yes)	Percentage (%)	Mean	SD	95% CI
Respiratory problems	214	50.1	0.50	0.50	0.45–0.55
Skin disease or dermatological problems	189	44.3	0.44	0.50	0.40–0.49
Musculoskeletal pain	258	60.4	0.60	0.49	0.56–0.65
Frequent work-related injuries	142	33.3	0.33	0.47	0.29–0.38

$N = 427$. The values represent the prevalence of self-reported health conditions among women waste pickers. Means represent the proportion of respondents who reported each health condition. Confidence intervals (CI) indicate the precision of the estimated prevalence rates.

Overall, the correlation analysis provides preliminary support for the hypothesized relationships among occupational exposure, social exclusion, welfare support, and health vulnerability, and suggests that the independent variables are sufficiently distinct to be included in the regression model simultaneously.

5.6 Multicollinearity diagnostics

Before estimating the ordinal logistic regression model, multicollinearity diagnostics were conducted to assess the degree of intercorrelation among the predictor variables. Examining multicollinearity is an important step in regression modeling because highly correlated predictors can distort coefficient estimates, inflate standard errors, and reduce the stability and interpretability of the model. Therefore, variance inflation factors (VIFs) and tolerance statistics were calculated to assess whether the independent variables exhibited problematic multicollinearity. Table 7 presents the multicollinearity diagnostics for all predictors included in the regression model.

The results indicate that multicollinearity was not a concern in the present analysis. The VIF values ranged from 1.05 to 1.27, which are well below the commonly accepted threshold of five, suggesting that the predictor variables do not exhibit strong linear relationships with one another. Similarly, the tolerance values ranged between 0.79 and 0.95, all of which comfortably exceeded the recommended minimum threshold of 0.20.

Among the predictors, years of waste picking showed the highest VIF value (1.27), followed by age (1.22). However, these values remained very low and were not statistically significant. The key explanatory variables—occupational exposure, social exclusion, and welfare support—also displayed very low VIF values (1.10, 1.07, and 1.05, respectively), confirming that these variables were sufficiently independent to include in the regression model.

Overall, the multicollinearity diagnostics demonstrate that the explanatory variables included in the analysis do not exhibit problematic inter-correlations. This confirms that the regression coefficients estimated in the subsequent ordinal logistic regression model can be confidently interpreted.

5.7 Ordinal logistic regression predicting health vulnerability among women waste pickers

To examine the determinants of health vulnerability among women waste pickers, an ordinal logistic regression model was estimated. This modelling approach is appropriate because the dependent variable, health vulnerability, represents ordered categories that reflect increasing levels of health risk. The regression analysis evaluates the effects of occupational exposure, social exclusion, and welfare support on health vulnerability while controlling for key demographic and occupational characteristics, including age, education, monthly income, and years of work in waste picking. This analysis enables us to assess the extent to which structural occupational and social factors influence the likelihood of experiencing higher levels of health vulnerability.

Table 8 presents the results of the ordinal logit regression model. Based on these findings, occupational exposure significantly increases the health vulnerabilities of female waste pickers. The coefficient for the occupational exposure index was positive and statistically significant ($\beta = 0.27$, $p = 0.001$), with an odds ratio of 1.31. This suggests that each additional unit increase in occupational exposure is associated with approximately a 31% higher odds of experiencing a higher level of health vulnerability. This indicates a clear increase in the likelihood of greater health vulnerability as exposure intensifies. This result highlights the substantial health risks associated with hazardous working environments in informal waste management systems. These findings provide empirical support for Hypothesis 1, which proposes that higher levels of occupational exposure increase the health vulnerability of female waste pickers.

Similarly, social exclusion is positively associated with health vulnerabilities. The Social Exclusion Index shows a statistically significant positive coefficient ($\beta = 0.12$, $p = 0.017$), with an odds ratio of 1.13. Waste women waste pickers who experience stigma, harassment, and discrimination more frequently face a higher level of health vulnerability. This result confirms Hypothesis 2, which predicts that social exclusion is positively associated with health vulnerability.

TABLE 6 Correlation matrix of key study variables ($N = 427$).

Variable	1	2	3	4	5	6	7
1. Occupational Exposure Index	1						
2. Social Exclusion Index	0.18**	1					
3. Welfare Support Score	-0.12*	-0.09	1				
4. Health Vulnerability Index	0.21**	0.17**	-0.14*	1			
5. Age	0.05	0.07	-0.03	0.09	1		
6. Education	-0.08	-0.11*	0.13*	-0.10	-0.06	1	
7. Years of Work	0.26**	0.12*	-0.07	0.18**	0.41**	-0.05	1

Values are Pearson's correlation coefficients. * $p < 0.05$, ** $p < 0.01$.

In contrast, welfare support has a protective effect on health vulnerabilities. The welfare support score has a negative coefficient, $\beta = -0.18$, with a p -value of 0.011 and an odds ratio of 0.84. Greater health vulnerability is less likely when welfare support is higher. In other words, increased access to welfare assistance and support mechanisms may mitigate the adverse health effects associated with hazardous working conditions and social marginalization. Thus, this supports Hypothesis 3, which posits that welfare support reduces health vulnerability among female waste pickers.

Among the control variables, years of waste picking were significantly and positively associated with health vulnerability ($\beta = 0.05$, $p = 0.024$; OR = 1.05), although the association was weak. This suggests that prolonged engagement in waste-picking activities may gradually increase cumulative health risks. In contrast, age, education, and monthly income were not statistically significantly associated with health vulnerability in the model, indicating that structural occupational and social factors play a more prominent role than individual demographic characteristics in explaining health vulnerability in this cohort.

The regression results indicate that health vulnerability is significantly enhanced by occupational exposure and social exclusion, and welfare support has a protective effect among women waste pickers. There is significant evidence that social contexts and workplace conditions impact the health of workers in these communities.

5.8 Model fit and diagnostic tests for the ordinal logistic regression model

Following the estimation of the ordinal logistic regression model, additional diagnostic tests were conducted to evaluate the model's adequacy and validity. Assessing model fit and testing the proportional odds assumption are essential steps in ordinal logistic regression, as they ensure that the model appropriately represents the relationship between the predictors and the outcome variable. These diagnostics help determine whether the model provides a statistically meaningful improvement over the null model and whether the assumptions underlying the ordinal regression framework are satisfied.

Table 9 presents the model fit statistics and diagnostic tests for the ordinal logistic regression model. The results indicate that the overall model provides a statistically significant improvement compared to the null model, which contains no predictors. The likelihood ratio chi-square test yields a value of 39.52 ($df = 7$, $p < 0.001$), demonstrating that the set of explanatory variables included in the model significantly improves the prediction of health vulnerability among women

TABLE 7 Multicollinearity diagnostics for regression model ($N = 427$).

Predictor variable	Tolerance	VIF
Occupational Exposure Index	0.91	1.10
Social Exclusion Index	0.93	1.07
Welfare Support Score	0.95	1.05
Age	0.82	1.22
Education	0.88	1.14
Monthly Income	0.90	1.11
Years of Work in Waste Picking	0.79	1.27

Variance Inflation Factor (VIF) values below 5 indicate that multicollinearity is not a concern in the regression model. Tolerance values above 0.20 also suggest that the predictors did not exhibit problematic intercorrelations.

waste pickers. This result confirms that the independent variables collectively explain variation in the outcome variable.

The log-likelihood value of -412.67 reflects the model's fit to the observed data and is consistent with the likelihood ratio test results, indicating a meaningful improvement over the baseline model. The McFadden pseudo R^2 of 0.11 indicates a modest level of explanatory power, which is typical in social and public health research, where health outcomes are influenced by broader structural and contextual factors not fully captured by the model.

An important assumption of ordinal logistic regression is the proportional odds (parallel lines) assumption, which requires that the relationship between the predictors and outcome variable remains consistent across different thresholds of the ordered categories. The test of parallel lines produced a non-significant result ($\chi^2 = 9.14$, $df = 7$, $p = 0.244$), indicating that the proportional odds assumption was met. This finding confirms that the ordinal logistic regression model is appropriate for this data.

Additional model selection criteria supported the model's adequacy. The Akaike information criterion (AIC) and Bayesian information criterion (BIC) values of 841.34 and 873.62, respectively, serve as indicators of model fit for comparing alternative model specifications. Lower values of these statistics generally indicate a better model fit.

Overall, the diagnostic tests demonstrated that the ordinal logistic regression model satisfied key statistical assumptions and provided a reliable framework for examining the determinants of health vulnerability among women waste pickers.

TABLE 8 Ordinal logistic regression predicting health vulnerability among women waste pickers ($N = 427$).

Predictor variable	β	Std. error	Odds ratio	95% CI	p -value
Occupational Exposure Index	0.27	0.08	1.31	1.12–1.53	0.001**
Social Exclusion Index	0.12	0.05	1.13	1.02–1.26	0.017*
Welfare Support Score	−0.18	0.07	0.84	0.73–0.96	0.011*
Age	0.01	0.01	1.01	0.99–1.03	0.264
Education	−0.14	0.10	0.87	0.71–1.07	0.156
Monthly Income	−0.0001	0.0001	0.99	0.99–1.00	0.201
Years of Work in Waste Picking	0.05	0.02	1.05	1.01–1.10	0.024*

Odds ratios indicate the change in the odds of experiencing higher levels of health vulnerability associated with a one-unit increase in the predictor variable. Positive coefficients indicated increased vulnerability, whereas negative coefficients indicated a protective effect. * $p < 0.05$, ** $p < 0.01$.

TABLE 9 Model fit and diagnostic tests for the ordinal logistic regression model ($N = 427$).

Diagnostic statistic	Value	df	p -value
Log Likelihood	−412.67		
Likelihood Ratio χ^2 (Model vs. Null Model)	39.52	7	<0.001
McFadden Pseudo R^2	0.11		
Test of Parallel Lines (Proportional Odds Assumption)	9.14	7	0.244
Akaike Information Criterion (AIC)	841.34		
Bayesian Information Criterion (BIC)	873.62		

The likelihood ratio test compares the fitted model to a null model containing no predictors. A statistically significant result indicated that the model fit better than the null model. The parallel lines test evaluates the proportional odds assumption underlying the ordinal logistic regression model. The non-significant result ($p = 0.244$) suggests that the proportional odds assumption was satisfied. Lower AIC and BIC values indicate a better model fit.

5.9 Predicted probability of health vulnerability across occupational exposure levels

The regression coefficients establish a statistical link between exposure and disease outcome or health vulnerability. However, predicted probability estimates allow for greater interpretability of these effects. Predicted probabilities illustrate how the likelihood of experiencing different levels of health vulnerability changes as occupational exposure increases, while holding other variables in the model constant. This approach helps translate regression findings into the actual effect of hazardous workplace conditions on the health of female waste pickers.

The estimated predicted probabilities reinforce the finding that working in hazardous conditions significantly increases the health problems faced by female waste workers. Exposure to biomedical waste, sharp objects, chemical materials, and burning waste without protection increases the risk of health problems.

The analysis, based on predicted probabilities, is a strong visual indicator, showing that occupational exposure is critical in determining the health vulnerability of the informal waste-picking system. The regression findings are reinforced by Figure 2. It shows how incremental increases in exposure lead to progressively higher odds of experiencing severe health vulnerability. These findings highlight the importance of improving occupational safety conditions and providing adequate protective measures for women engaged in informal recycling activities.

6 Discussion

This study examined the factors contributing to the health vulnerability of women involved in informal waste picking in urban

recycling systems. The results show that the health risk of women waste pickers is associated with the interaction between occupational exposure, social exclusion, welfare support, and work experience within broader environmental, social, and institutional conditions. Thus, this study extends research on informal waste economies by demonstrating that health vulnerability cannot be reduced to an occupational risk. Instead, it must be interpreted through the lens of various social and structural inequalities in informal labor spheres. By integrating occupational exposure, social exclusion, and welfare support into a unified analytical framework, this study advances environmental justice and informal labor scholarship by providing empirical evidence that health vulnerability arises from the interaction of multiple structural conditions rather than from isolated risk factors. This study offers a distinct contribution by empirically demonstrating how occupational, social, and institutional dimensions interact to produce health vulnerability, rather than operating as independent risk factors. Interpreted through the environmental justice framework, the findings reflect structured inequality in the distribution of environmental risks and social protections. Women waste pickers experience a disproportionate concentration of environmental burdens in the form of hazardous occupational exposure, while simultaneously facing social exclusion and limited access to institutional support. This co-occurrence reflects both distributive injustice (unequal exposure to environmental risks) and procedural injustice (limited access to decision-making, welfare systems, and institutional protections), reinforcing patterns of health vulnerability among marginalized workers (Das, 2025; Mohai et al., 2009).

The study revealed that occupational exposure and health vulnerability were strongly associated. The health vulnerability of women waste pickers is significantly associated with exposure to hazardous materials, including biomedical waste, chemical residues, sharp objects, and smoke from burning waste. These occupational health

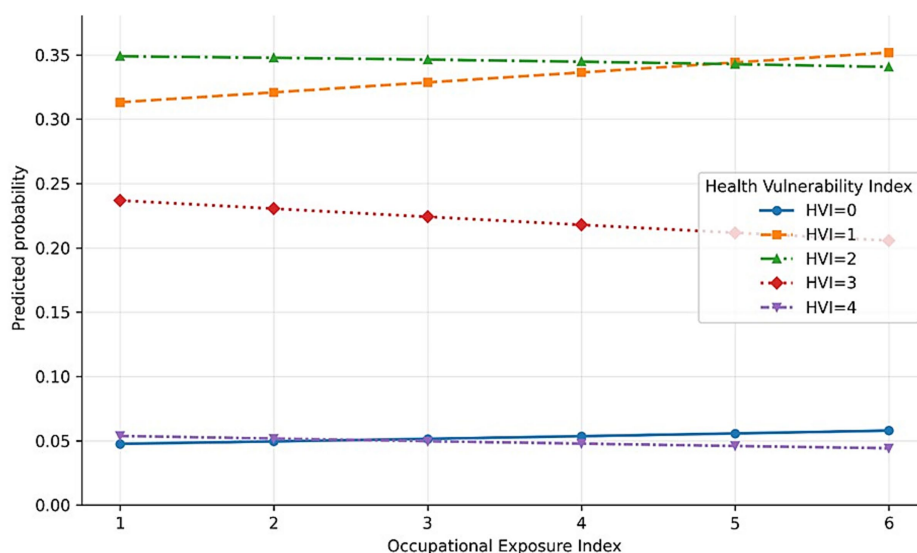


FIGURE 2

Presents a clear pattern indicating that higher levels of occupational exposure are associated with a higher probability of experiencing greater health vulnerability. As occupational exposure increases, the predicted probability of falling into higher vulnerability categories rises steadily, while the probability of remaining in lower vulnerability categories declines. This pattern is consistent with the regression analysis results in Table 8, where occupational exposure was significantly and positively associated with health vulnerability.

risks align with existing literature identifying them for informal waste workers, who often work on the 'dirty side' of a landfill, handling mixed waste and unsegregated contamination. Workers have limited access to personal protective equipment (Cruvinel et al., 2019; Zolnikov et al., 2021; Uhumamure et al., 2021). Under such conditions, workers are often exposed to biological agents daily. In addition, there are also toxic substances and physical hazards that cause respiratory ailments. Besides, they suffer from dermatological infections. Not to forget, accidental injuries. Therefore, the results reinforce the growing evidence that informal recycling systems often rely on labor performed under environmentally hazardous conditions, placing workers' health at considerable risk. While existing studies have predominantly examined occupational hazards, social marginalization, or welfare access in isolation, the present study makes a novel contribution by empirically demonstrating how these dimensions operate simultaneously to shape health outcomes among women waste pickers. From an environmental justice perspective, this pattern reflects disproportionate exposure to environmental hazards among marginalized workers who contribute to urban sustainability yet remain unprotected from the associated risks (Mohai et al., 2009).

The findings indicate that, in addition to occupational exposure, social exclusion is significantly associated with the health vulnerability of women waste pickers. Participants who reported higher levels of social marginalization—including stigma, discrimination, and limited access to community resources—were more likely to experience poorer health outcomes. This observation is consistent with broader sociological evaluations of informal labor, which highlight the social stigma surrounding waste pickers in urban economies and their exclusion from formal social protection. Worldwide, waste picking is associated with poverty and marginalization based on caste, class, or ethnicity and gender-based inequalities. These findings highlight the importance of an intersectional perspective, in which gender intersects with class position, caste-based marginalization, and occupational precarity to produce layered and compounded forms of vulnerability among women waste pickers (Wittmer, 2020;

Shanmugasundaram, 2024; Coletto et al., 2017). These factors reinforce isolation and limit access to services, such as healthcare, sanitation, and housing. Within the environmental justice framework, such patterns reflect not only social marginalization but also procedural inequalities, in which affected populations have limited access to institutional resources, recognition, and protective mechanisms (Kaufman and Hajat, 2021). The social status of waste work can increase occupational hazards by making workers less likely to seek medical care or request better working conditions. Consequently, the study finds that the health vulnerability of waste pickers cannot be limited to environmental or workplace issues. Deeper inequalities in informal labor may also surface through them.

In contrast to these risk factors, welfare support emerged as an important protective factor associated with lower health vulnerability among women waste pickers. Participants who reported access to welfare benefits, community assistance, or basic health services were less likely to experience severe health risks. This finding is consistent with research suggesting that social protection mechanisms can play a critical role in mitigating health inequalities among marginalized populations (Bocean and Vărzaru, 2024; Gutberlet and de Vallin, 2025; Chan et al., 2025). Welfare support can facilitate access to healthcare services, improve living conditions, and reduce economic pressure that often forces workers to remain in unsafe occupational environments. In several cities, initiatives that recognize and support waste pickers, such as cooperative recycling programs and municipal partnerships, have improved worker welfare and recycling efficiency (Wilson et al., 2005; Barford et al., 2021; Yang et al., 2017). The results of the present study highlight the importance of institutional support systems in reducing health vulnerabilities among informal waste workers. This finding aligns with the environmental justice perspective, illustrating how access to institutional support can mitigate inequalities in the distribution of environmental and health risks.

The analysis also suggests that the duration of waste-picking contributes to cumulative health risks. Workers with more experience in the sector are more likely to report higher health vulnerability,

suggesting that prolonged occupational exposure may gradually undermine workers' physical health. Previous studies have similarly noted that repeated exposure to hazardous waste materials, combined with physically demanding working conditions, can produce long-term health effects that accumulate over time (Zolnikov et al., 2021; Cruvinel et al., 2019; Maneen et al., 2025). Without adequate protective measures, regular medical monitoring, or access to healthcare services, these cumulative exposures may lead to chronic illnesses that further reinforce waste pickers' economic and social vulnerability.

The findings of this study contribute to the broader debates on environmental justice and sustainability in urban waste systems. Informal waste pickers collect recyclable waste, which helps the circular economy function. The efforts made by such workers minimize pressure on landfills, enhance the recovery of resources, and contribute to the environmental sustainability of numerous towns and cities (Alpha et al., 2025; Binion and Gutberlet, 2012; Marelllo and Helwege, 2017; Neville et al., 2023). However, the environmental benefits generated by informal recycling systems often come at the expense of workers' health and wellbeing. Waste pickers typically face environmental hazards associated with waste management, with little institutional recognition or protection. This imbalance reflects broader patterns of environmental injustice characterized by the disproportionate exposure of marginalized populations to environmental hazards while contributing significantly to environmental services (Tucker and Anantharaman, 2020; Kain et al., 2022).

From a sustainability perspective, the results underscore the need to integrate informal waste workers into formal waste governance frameworks. Rather than treating waste picking as an informal survival activity, policymakers should recognize the sector as an integral component of urban recycling systems. Policies that provide safety equipment, improve access to health services, and support waste picker cooperatives are likely to enhance female waste-pickers' welfare and efficiency (Sesay and Fang, 2025; Marelllo and Helwege, 2017; Schenck et al., 2019). Such initiatives not only contribute to more equitable labor conditions but also strengthen the sustainability of urban recycling infrastructures by acknowledging the contributions of informal waste workers.

Overall, the findings demonstrate that health vulnerability among women waste pickers is associated with the combined influence of hazardous occupational environments, social marginalization, and limited welfare support. Addressing these challenges requires a multidimensional policy response that integrates occupational health protection, social inclusion and sustainable waste governance. By highlighting the interconnectedness of environmental exposure, social exclusion, and institutional support, this study contributes to ongoing efforts to promote a more inclusive and equitable sustainability transition in urban waste management systems. Taken together, these findings reinforce the relevance of environmental justice as an analytical framework for understanding how environmental risks, social inequalities, and institutional gaps intersect to shape health outcomes in the informal labor system.

6.1 Policy and sustainability implications

The findings of this study have important implications for public policy, urban governance, and sustainability planning. Women waste pickers represent a critical, yet often overlooked, component of urban recycling systems. The work they perform plays a notable role in recovering resources and reducing waste, which is part of circular

waste economies in many cities (Alpha et al., 2025). However, as the present findings demonstrate, the environmental benefits generated through informal recycling are frequently accompanied by substantial health risks and social vulnerabilities for the workers. Addressing this imbalance requires policy frameworks that recognize waste pickers not merely as informal labourers but as key actors within sustainable waste management systems.

A significant implication is bolstering protections for the occupational health of informal waste workers. A strong relationship between occupation and health vulnerability indicates that hazardous working conditions remain an important determinant of health risk among women waste pickers. Consequently, action should be taken to ensure minimum direct exposure to these dangerous waste materials by municipal authorities and waste management agencies. These measures may include better segregation at the source (UNEP, 2016), provision of protective equipment, and safer waste collection and sorting infrastructure (Han et al., 2022). Such interventions should be operationalized through structured municipal programs that include regular provision of protective equipment, periodic occupational health screening, targeted safety training, and institutional accountability mechanisms to ensure sustained implementation. Previous studies have shown that simple occupational safety measures, such as gloves, protective clothing, and designated sorting areas, can significantly reduce the health hazards of informal recycling (Baral, 2018; Cruvinel et al., 2019). By implementing such interventions, not only would workers' health be safeguarded, but the efficiency and safety of urban waste management systems would also be enhanced.

A second policy implication concerns the need to extend social protection to waste pickers. According to this study, welfare support has a protective effect, meaning that access to social assistance programs may reduce the health vulnerabilities of marginalized workers. Expanding access to health services and health insurance schemes (Chokhandre et al., 2017), and other community-based welfare programs can significantly enhance the wellbeing of workers engaged in informal waste recovery (Kistan et al., 2020). Evidence from institutional arrangements in diverse countries suggests that incorporating waste pickers into cooperatives or municipal recycling programs can enhance their economic resilience and access to social services (Ogando et al., 2017). Through select initiatives, institutional channels can be established to ensure workers receive due recognition, social protection, and safer working conditions.

The results also indicate that social stigma and the marginalization of waste pickers must be addressed. Social exclusion is a strong predictor of health vulnerability. Thus, waste pickers' health is affected not only by the impoverishing environmental conditions but also by how they are perceived and by the barriers that higher institutions erect.

Public awareness campaigns, community engagement initiatives, and inclusive waste governance strategies may therefore play an important role in reducing the social marginalization faced by waste pickers. One way to challenge the negative perceptions of scavengers is to change public perceptions through recognition, to include them more in social inclusion in cities (Coletto et al., 2017; Tucker and Anantharaman, 2020).

Similarly, the results indicate the need to include informal recycling systems in sustainable urban development interventions. Waste pickers' contributions to recycling and resource recovery in various cities are substantial. Most of the time, they work in settings where formal waste management systems are insufficient (Wilson et al., 2005; Marelllo and Helwege, 2017). The inclusion of waste pickers in formal

policies of waste management through cooperative organizations, municipal partnerships, or inclusive initiatives of the circular economy can enhance environmental sustainability while improving the livelihoods of marginalized workers. These approaches illustrate a more comprehensive model of sustainability that acknowledges the social aspects of environmental governance and seeks equity in addition to environmental results.

6.2 Limitations and future research directions

This study had several limitations that should be considered when interpreting the findings. First, the cross-sectional nature of the study limits the degree of temporal ordering of the variables. Thus, the associations observed between occupational exposure, social exclusion, welfare support, and health vulnerability should be considered statistical associations and not causal effects. Although the analysis identified significant relationships, it did not permit conclusions regarding directionality or causation.

Second, the purposive sampling technique, while appropriate for accessing a hard-to-reach population, may limit the generalizability of the findings beyond the study. The sample may not fully represent the broader conditions of informal waste picking across different geographical, socioeconomic and institutional settings. In particular, this study is situated within a specific regional context in Tamil Nadu, India, and the findings should be interpreted with reference to these contextual conditions. While the results offer analytically relevant insights, they may not be directly generalizable to other regions with different policy environments or socio-economic structures.

Third, the study used self-reported data from structured interviews, which may be subject to reporting bias and common method variance. The potential for response bias was minimized but not eliminated during the data collection.

Despite these limitations, this study provides important empirical insights into the structural determinants of health vulnerability among women waste pickers. This research could be extended in the future using a longitudinal or panel study design to explore temporal dynamics and investigate causal pathways more robustly than in this study. Furthermore, qualitative and mixed-methods research may shed additional light on the lived experiences and intersectional aspects of vulnerability in informal waste economies.

highlight the multidimensional nature of health inequalities within informal labor systems and underscore the importance of addressing both environmental and social health determinants.

This study contributes to the existing literature on informal waste economies by providing empirical evidence of the interconnected effects of occupational risk, social marginalization, and welfare access on workers' health vulnerability. Through analysis of these results, this study reveals that the impact of urban recycling and resource recovery on informal waste workers is linked to broader debates on environmental justice and sustainability. Beyond its policy relevance, this study contributes to environmental justice scholarship by demonstrating that health vulnerability emerges from the interaction of occupational, social, and institutional inequalities. In this sense, informal waste picking is both an important environmental service and a site of social inequality in the contemporary urban system.

These findings indicate the need for more inclusive and equitable waste governance approaches. The working conditions of waste pickers may be substantially improved by strengthening occupational health protections, expanding access to social welfare programs, and providing official recognition within municipal recycling systems. Integrating informal waste workers into sustainable waste management frameworks may offer a pathway toward more equitable and resilient urban sustainability transitions.

This study emphasizes that the health vulnerability experienced by women waste pickers must be addressed through a multifaceted policy approach that encompasses occupational health and safety, social protection, and inclusive governance. Policymakers and urban planners can help protect environmental resources and the people's livelihoods linked to them by recognizing the integral role of informal waste workers in urban recycling systems and by implementing sustainable, socially just urban waste management practices. Future research should extend this work by employing longitudinal designs to examine changes in health vulnerability over time, and comparative and qualitative approaches to capture better the lived experiences and structural dynamics of informal waste work. These findings should also be interpreted within the specific regional context of Tamil Nadu, India, and may not be directly generalizable to other settings in India.

However, given the cross-sectional nature of the data, these findings should be interpreted as indicative of statistical associations, rather than causal relationships. This study did not establish temporal ordering or causal directionality between the variables. Future research employing longitudinal or panel designs is necessary to examine causal pathways and dynamic relationships more rigorously.

7 Conclusion

This study contributes to the literature by providing an integrated empirical analysis of how occupational exposure, social exclusion, and welfare support shape health vulnerability among women waste pickers. This study investigates the determinants of health vulnerability among women waste pickers working in the informal recycling sector, focusing on occupational exposure, social exclusion, welfare support, and work experience. The results show that health vulnerability in informal waste economies is strongly associated with hazardous working conditions, structural social marginalization and limited access to institutional support systems. Women waste pickers who experience greater exposure to hazardous waste materials and higher levels of social exclusion tend to report higher health risks, whereas access to welfare support is associated with lower levels of reported health vulnerability. These results

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the Institutional Review Board of Marian College, Kuttikkanam (Approval number: MCKA/IERB/010326). The studies were conducted in accordance with the local legislation and institutional requirements. The

participants provided their written informed consent to participate in this study.

Author contributions

AK: Methodology, Supervision, Conceptualization, Writing – original draft, Formal analysis, Writing – review & editing. RR: Formal analysis, Writing – review & editing, Conceptualization, Writing – original draft, Validation. NV: Writing – original draft, Writing – review & editing, Formal analysis, Methodology, Supervision. JB: Writing – review & editing, Writing – original draft, Methodology, Investigation. KS: Methodology, Writing – review & editing, Formal analysis, Writing – original draft. VM: Data curation, Investigation, Conceptualization, Writing – review & editing, Writing – original draft. MR: Writing – review & editing, Conceptualization, Data curation, Writing – original draft, Investigation, Visualization.

Funding

The author(s) declared that financial support was not received for this work and/or its publication.

Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

- Addas, A., Khan, M. N., and Naseer, F. (2024). Waste management 2.0 leveraging internet of things for an efficient and eco-friendly smart city solution. *PLoS One* 19:307608. doi: 10.1371/journal.pone.0307608
- Alpha, K., Rebecca, S., and James, E. (2025). *Informal Waste pickers in Africa: social Reproduction, Marginalization and Sustainability*. London: Figshare.
- Anshur, Y. A. A., Sheik, A. M., Roble, M. A., Yasin, A. M., Mohamed, A. A., Mohamud, F. A., et al. (2024). Prevalence of occupational injury and knowledge of post-exposure prophylaxis accessibility among healthcare workers in Mogadishu, Somalia. *Occup. Dis. Environ. Med.* 12, 172–198. doi: 10.4236/odem.2024.123014
- Aparcana, S. (2016). Approaches to formalization of the informal waste sector into municipal solid waste management systems in low- and middle-income countries: review of barriers and success factors. *Waste Manag.* 61, 593–607. doi: 10.1016/j.wasman.2016.12.028
- Baral, Y. R. (2018). Waste workers and occupational health risks. *Int. J. Occup. Safety Health* 8, 1–3. doi: 10.3126/ijosh.v8i2.23328
- Barford, A., and Ahmad, S. R. (2021). A call for a socially restorative circular economy: waste pickers in the recycled plastics supply chain. *Circ. Econ. Sustain.* 1, 761–782. doi: 10.1007/s43615-021-00056-7
- Binion, E., and Gutberlet, J. (2012). The effects of handling solid waste on the wellbeing of informal and organized recyclers: a review of the literature. *Int. J. Occup. Environ. Health* 18, 43–52. doi: 10.1179/1077352512z.0000000001
- Bocean, C. G., and Vărzaru, A. A. (2024). Assessing social protection influence on health status in the European Union. *Front. Public Health* 12:608. doi: 10.3389/fpubh.2024.1287608
- Chan, S., Tang, Y., Xu, H. Y., Zhang, J., Kwok, K., Tam, N. W. Y., et al. (2025). Unequal burdens: gendered and socioeconomic dimensions of occupational health among Hong Kong's informal waste pickers. *Healthcare* 13:683–683. doi: 10.3390/healthcare13060683
- Chokhandre, P., Singh, S. K., and Kashyap, G. C. (2017). Prevalence, predictors and economic burden of morbidities among waste-pickers of Mumbai, India: a cross-sectional study. *J. Occup. Med. Toxicol.* 12:176. doi: 10.1186/s12995-017-0176-3
- Coletto, D., and Bisschop, L. (2017). Waste pickers in the informal economy of the global south: included or excluded? *Int. J. Sociol. Soc. Policy* 37, 280–294. doi: 10.1108/ijssp-01-2016-0006
- Coletto, D., and Carbonai, D. (2023). What does it mean to have a dirty and informal job? The case of waste pickers in the Rio Grande do Sul, Brazil. *Sustainability* 15, 2337–2337. doi: 10.3390/su15032337
- Cook, E., Woolridge, A. C., Stapp, P., Edmondson, S., and Velis, C. A. (2022). Medical and healthcare waste generation, storage, treatment and disposal: a systematic scoping review of risks to occupational and public health. *Crit. Rev. Environ. Sci. Technol.* 53, 1452–1477. doi: 10.1080/10643389.2022.2150495
- Cruvinel, V. R. N., Marques, C. P., Cardoso, V. E., Novaes, M. R. C. G., Araújo, W. N., Angulo-Tuesta, A., et al. (2019). Health conditions and occupational risks in a novel group: waste pickers in the largest open garbage dump in Latin America. *BMC Public Health* 19:6879. doi: 10.1186/s12889-019-6879-x
- Cruz, U. R. X., García, R. A., and Díaz, M. A. (2025). Urban solid waste management and social inclusion: challenges and perspectives in Latin America. *Rev. Gest. Soc. E Ambient.* 19:106. doi: 10.24857/rgsa.v19n4-106
- Das, D. K. (2025). Exploring the intersection of environmental justice and urban green space planning: a systematic review. *Urban Sci.* 9:540. doi: 10.3390/urbansci9120540
- Dias, S. M. (2016). Waste pickers and cities. *Environ. Urban.* 28, 375–390. doi: 10.1177/0956247816657302
- Fergutz, O., Dias, S., and Mitlin, D. (2011). Developing urban waste management in Brazil with waste picker organizations. *Environ. Urban.* 23, 597–608. doi: 10.1177/0956247811418742

Generative AI statement

The author(s) declared that Generative AI was used in the creation of this manuscript. Paperpal and Grammarly was used to improve the grammar, spelling, and readability of the manuscript. The authors played a central role in the conception, data analysis, interpretation of results, and writing of the manuscript. The authors take overall responsibility for the contents of the manuscript.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/frsus.2026.1833366/full#supplementary-material>

- Flynn, M. A., Check, P., Steege, A. L., Sívén, J., and Syron, L. N. (2021). Health equity and a paradigm shift in occupational safety and health. *Int. J. Environ. Res. Public Health* 19:349–349. doi: 10.3390/ijerph19010349
- Fredman, S. (2023). Greening the workforce: a feminist perspective. *Int. J. Comp. Labour Law Ind. Relat.* 39, 337–358. doi: 10.54648/ijcl2023033
- Gandy, O. H. (2013). Wedging equity and environmental justice into the discourse on sustainability. *TripleC Commun. Capital Crit. Open Access J. Glob. Sustain. Inf. Soc.* 11, 221–236. doi: 10.31269/vol11iss1pp221-236
- Goh, K. C., Kurniawan, T. A., Othman, M. H. D., Anouzla, A., Aziz, F., Ali, I., et al. (2025). Reinforcing urban resilience through sound landfill management: addressing global climatic challenges with novel solutions. *Process. Saf. Environ. Prot.* 195:106789. doi: 10.1016/j.psep.2025.106789
- Gomes, A. V. M., and Neto, F. d. A. A. (2018). A POLÍTICA de INCLUSÃO dos CATADORES de RESÍDUOS SÓLIDOS: um ESTUDO NA CIDADE de FORTALEZA. *Rev. Direito. Cid.* 10:922. doi: 10.12957/rdc.2018.29922
- Gutberlet, J. (2009). Waste, poverty and recycling. *Waste Manag.* 30, 171–173. doi: 10.1016/j.wasman.2009.11.006
- Gutberlet, J. (2018). *Waste in the City: Challenges and Opportunities for Urban Agglomerations*. Rijeka: InTech EBooks.
- Gutberlet, J. (2023). Global plastic pollution and informal waste pickers. *Camb. Prisms Plast.* 11, 1–38. doi: 10.1017/plc.2023.10
- Gutberlet, J., and Carenzo, S. (2020). Waste pickers at the heart of the circular economy: a perspective of inclusive recycling from the global south. *Worldw. Waste* 3, 6–6. doi: 10.5334/wwwj.50
- Gutberlet, J., and de Vallin, I. (2025). “Grassroots social innovation of waste pickers as critique of the existing social order,” in *Waste as critique*, ed. H. Corvellec (Oxford: OUP), 144–168.
- Gutberlet, J., and Uddin, S. M. N. (2017). Household waste and health risks affecting waste pickers and the environment in low- and middle-income countries. *Int. J. Occup. Environ. Health* 23, 299–310. doi: 10.1080/10773525.2018.1484996
- Hadfield, P., Ningrum, D., Aditya, B., Hardesty, B. D., Holden, J., Maheshwari, T., et al. (2025). Transformative principles for circular economy transitions in the global south. *NPJ Urban Sustain.* 5:225. doi: 10.1038/s42949-025-00225-9
- Han, J., He, S., Shao, W., Wang, C., Qiao, L., Zhang, J., et al. (2022). Municipal solid waste, an overlooked route of transmission for the severe acute respiratory syndrome coronavirus 2: a review. *Environ. Chem. Lett.* 21, 81–95. doi: 10.1007/s10311-022-01512-y
- Hossain, I., and Haque, A. K. M. M. (2026). A systematic and bibliometric review on urban governance and circular economy pathways for municipal solid waste management in South Asia. *Discov. Cities* 3:195. doi: 10.1007/s44327-026-00195-2
- Izquierdo-Horna, L., and Camacho-Castañeda, D. (2022). Municipal solid waste generation: an exploratory analysis of consumption patterns in Peru. *WIT Trans. Ecol. Environ.* 1, 405–413. doi: 10.2495/sc220331
- Joseph, J. I., Chioma, N. M., and Joseph, J. I. (2026). The intersection of waste picking and health hazard: a study of waste picker's risky behaviour and public health outcomes in Nigerian cities. *J. Sust. Eng. Green Technol.* 2, 1–16. doi: 10.63456/fyd3jq07
- Kadyamadare, G., and Samson, M. (2023). Thinking households—how resident conceptualisations of waste, reclaimers and separation at source shape recycling practices. *Urban Forum* 35, 25–46. doi: 10.1007/s12132-023-09497-9
- Kain, J., Zapata, P., Azevedo, A. M. M., Carenzo, S., Charles, G., Gutberlet, J., et al. (2022). Characteristics, challenges and innovations of waste picker organizations: a comparative perspective between Latin American and east African countries. *PLoS One* 17:5889. doi: 10.1371/journal.pone.0265889
- Kaufman, J. D., and Hajat, A. (2021). Confronting environmental racism. *Environ. Health Perspect.* 129:51001. doi: 10.1289/ehp511
- Kistan, J., Ntlebi, V., Made, F., Kootbodien, T., Wilson, K., Tlotleng, N., et al. (2020). Health care access of informal waste recyclers in Johannesburg, South Africa. *PLoS ONE* 15:e0235173. doi: 10.1371/journal.pone.0235173
- Korsunova, A., Halme, M., Kourula, A., Levänen, J., and Lima-Toivanen, M. (2022). Necessity-driven circular economy in low-income contexts: how informal sector practices retain value for circularity. *Glob. Environ. Change* 76:102573–102573. doi: 10.1016/j.gloenvcha.2022.102573
- Kotsila, P., Anguelovski, I., Sekulova, F., and García-Lamarca, M. (2022). *Injustice in urban sustainability*. New York, NY: Taylor & Francis.
- Lissah, S. Y., Ayanore, M. A., Krugu, J. K., Aberese-Ako, M., and Ruiter, R. A. C. (2022). Our work, our health, no one's concern: domestic waste collectors' perceptions of occupational safety and self-reported health issues in an urban town in Ghana. *Int. J. Environ. Res. Public Health* 19:6539–6539. doi: 10.3390/ijerph19116539
- Made, F., Ntlebi, V., Kootbodien, T., Wilson, K., Tlotleng, N., Mathee, A., et al. (2020). Illness, self-rated health and access to medical care among waste pickers in landfill sites in Johannesburg, South Africa. *Int. J. Environ. Res. Public Health* 17, 2252–2252. doi: 10.3390/ijerph17072252
- Magalhães, E. J. L., Fernandes, M. A., Viana, M. R. P., Martins, M. d. C. d. C. e., Lago, E. C., Barbosa, D. A., et al. (2021). Health and work conditions of garbage collectors: a cross-sectional study. *Open Nurs. J.* 15, 319–325. doi: 10.2174/1874434602115010319
- Maneen, S., Botha, N. N., Amoadu, M., and Ansah, E. W. (2025). Psychosocial work factors influencing health, safety, well-being and productivity of waste collectors in developing countries: a scoping review. *BMC Psychol.* 13:885–885. doi: 10.1186/s40359-025-03251-5
- Marello, M., and Helwege, A. (2017). Solid waste management and social inclusion of waste pickers: opportunities and challenges. *Lat. Am. Perspect.* 45, 108–129. doi: 10.1177/0094582x17726083
- Masuda, J. R., and Crabtree, A. (2010). Environmental justice in the therapeutic inner city. *Health Place* 16, 656–665. doi: 10.1016/j.healthplace.2010.02.003
- Medina, M. (2010). *Solid wastes, poverty, and the environment in developing country cities: challenges and opportunities*. Oxford: Oxford University Press, 268–284.
- Misra, A., and Baheti, D. (2023). *Who Picks (Y)our Waste? Evidence-based Observations and Policy Priorities for Equitable Development*. New York, NY: UNDP, 3005–3307.
- Misra, R., and Tewari, N. (2022). Gender, migration, and precarity: a case study of migrant women waste pickers from Assam. *Indian J. Labour Econ.* 65, 1179–1192. doi: 10.1007/s41027-022-00411-8
- Mlotshwa, N., Dayaram, T., Khanyile, A., Sibanda, P. A., Erwin, K., and Fleetwood, T. (2022). Working with waste: hazards and mitigation strategies used by waste pickers in the inner city of Durban. *Int. J. Environ. Res. Public Health* 19, 12986–12986. doi: 10.3390/ijerph192012986
- Mohai, P., Pellow, D. N., and Roberts, J. T. (2009). Environmental justice. *Annu. Rev. Environ. Resour.* 34, 405–430. doi: 10.1146/annurev-environ-082508-094348
- Morais, J., Corder, G., Golev, A., Lawson, L., and Ali, S. H. (2022). Global review of human waste-picking and its contribution to poverty alleviation and a circular economy. *Environ. Res. Lett.* 17:63002. doi: 10.1088/1748-9326/ac6b49
- Navarrete-Hernández, P., and Navarrete-Hernandez, N. (2017). Unleashing waste-pickers' potential: supporting recycling cooperatives in Santiago de Chile. *World Dev.* 101, 293–310. doi: 10.1016/j.worlddev.2017.08.016
- Ncube, F., Ncube, E. J., and Vuyi, K. (2016). A systematic critical review of epidemiological studies on public health concerns of municipal solid waste handling. *Perspect. Public Health* 137, 102–108. doi: 10.1177/1757913916639077
- Neville, L., and Cortés, L. F. T. (2023). Waste pickers' formalisation from Bogotá to Cartagena de Indias: dispossession and socio-economic enclosures in two Colombian cities. *Sustainability* 15:9047. doi: 10.3390/su15119047
- Ogando, A. C., Roever, S., and Rogan, M. (2017). Gender and informal livelihoods. *Int. J. Sociol. Soc. Policy* 37, 435–451. doi: 10.1108/ijssp-06-2016-0077
- Parra, F. (2020). The struggle of waste pickers in Colombia: from being considered trash, to being recognised as workers. *Anti-Traffick. Rev.* 22, 122–136. doi: 10.14197/atr.201220157
- Poonkasem, N., Wibuloutai, J., Kongtip, P., and Chaiklieng, S. (2022). Musculoskeletal disorder among municipal solid waste collectors: a CASE study of SUNG NOEN district, NAKHON RATCHASIMA province. *J. Southwest Jiaotong Univ.* 57, 467–474. doi: 10.35741/issn.0258-2724.57.5.37
- Rani, U., Pandey, B. W., Saluja, D., Anand, S., and Kumar, H. (2023). Assessing the occupational and environmental health hazards among rag-pickers: a systematic review. *Res Sq Res Sq* 8, 1–5. doi: 10.21203/rs.3.rs-2564708/v1
- Rengerla, A., and Angamuthu, P. (2025). Evolving dynamics of municipal solid waste management in India: a comprehensive review of status, challenges, opportunities and policy innovations. *Waste Disposal Sust. Energy* 7, 127–150. doi: 10.1007/s42768-024-00220-3
- Schenck, R., Blaauw, D., Viljoen, K., and Swart, R. (2019). Exploring the potential health risks faced by waste pickers on landfills in South Africa: a socio-ecological perspective. *Int. J. Environ. Res. Public Health* 16, 2059–2059. doi: 10.3390/ijerph16112059
- Sesay, R. E. V., and Fang, P. (2025). Circular economy in municipal solid waste management: innovations and challenges for urban sustainability. *J. Environ. Prot.* 16, 35–65. doi: 10.4236/jep.2025.162003
- Shanmugasundaram, L. (2024). Waste picking in the age of COVID-19: an environmental justice perspective. *Discov. Environ.* 2:95. doi: 10.1007/s44274-024-00095-5
- Sharholi, M., Ahmad, K., Mahmood, G., and Trivedi, R. C. (2007). Municipal solid waste management in Indian cities – a review. *Waste Manag.* 28, 459–467. doi: 10.1016/j.wasman.2007.02.008
- Sharma, S. (2023). GEOGRAPHIES OF EXCLUSION: reproducing dispossession and erasure within a waste picker organization in Mumbai. *Int. J. Urban Reg. Res.* 47, 861–875. doi: 10.1111/1468-2427.13204
- Sibanda, P. A., and Erwin, K. (2023). Women's stories of waste picking in the city: “people look at us like we are mad, but I don't care.”. *Soc. Health Sci.* 22:13833. doi: 10.25159/2957-3645/13833
- Tshivhase, S., Mashau, N. S., Ngobeni, T., and Ramathuba, D. U. (2022). Occupational health and safety hazards among solid waste handlers at a selected municipality South Africa. *Health SA Gesondheid* 27:1978–1978. doi: 10.4102/hsag.v27i0.1978
- Tucker, J., and Anantharaman, M. (2020). Informal work and sustainable cities: from formalization to repairation. *One Earth* 3, 290–299. doi: 10.1016/j.oneear.2020.08.012
- Uhunamure, S. E., Edokpayi, J. N., and Shale, K. (2021). Occupational health risk of waste pickers: a case study of northern region of South Africa. *J. Environ. Public Health* 2021, 1–12. doi: 10.1155/2021/5530064

UNEP (2016). *Global Waste Management Outlook*. London: United Nations.

Velis, C. A. (2017). Waste pickers in global south: informal recycling sector in a circular economy era. *Waste Manag. Res.* 35, 329–331. doi: 10.1177/0734242x17702024

Vimercati, L., Baldassarre, A., Gatti, M. F., Maria, L. D., Caputi, A., Dirodi, A. A., et al. (2016). Respiratory health in waste collection and disposal workers. *Int. J. Environ. Res. Public Health* 13, 631–631. doi: 10.3390/ijerph13070631

Vivan, K. (2025). Socio-economic contributions of informal waste pickers to urban waste management. *J. Sust. Manage. Soc. Prog.* 1, 37–43. doi: 10.64229/6stw7245

Wibin, P., and Kalina, M. (2025). Informal waste pickers and non-motorized transport: a mini-review of contemporary literature. *Waste Manag. Res. J. Sustain. Circ. Econ.* 44, 154–165. doi: 10.1177/0734242x251361730

Wilson, D. C., Araba, A. O., Chinwah, K., and Cheeseman, C. (2008). Building recycling rates through the informal sector. *Waste Manag.* 29, 629–635. doi: 10.1016/j.wasman.2008.06.016

Wilson, D. C., Velis, C. A., and Cheeseman, C. (2005). Role of informal sector recycling in waste management in developing countries. *Habitat Int.* 30, 797–808. doi: 10.1016/j.habitatint.2005.09.005

Wittmer, J. (2020). We live and we do this work: women waste pickers' experiences of wellbeing in Ahmedabad, India. *World Dev.* 140:105253–105253. doi: 10.1016/j.worlddev.2020.105253

Yang, H., Ma, M., Thompson, J. R., and Flower, R. J. (2017). Waste management, informal recycling, environmental pollution and public health. *J. Epidemiol. Community Health* 72, 237–243. doi: 10.1136/jech-2016-208597

Zhang, Z., Chen, Z., Zhang, J., Liu, Y., Chen, L., Yang, M., et al. (2024). Municipal solid waste management challenges in developing regions: a comprehensive review and future perspectives for Asia and Africa. *Sci. Total Environ.* 930:172794–172794. doi: 10.1016/j.scitotenv.2024.172794

Zolnikov, T. R., Furio, F., Cruvinel, V. R. N., and Richards, J. (2021). A systematic review on informal waste picking: occupational hazards and health outcomes. *Waste Manag.* 126, 291–308. doi: 10.1016/j.wasman.2021.03.006