

Assessment of Electronic Waste Management Environmental Pollution and Associated Health Risks in Gazipur City Bangladesh

Md Faruque Hossain

19271002@student.duet.ac.bd

Dhaka University of Engineering & Technology

Md.Rabiul Islam

Dhaka University of Engineering & Technology

Alamgir Ahmed

Dhaka University of Engineering & Technology

Md. Biplob Hosen

Dhaka University of Engineering & Technology

Research Article

Keywords: Electronic waste, Material Flow Analysis, Informal recycling, Circular economy, Environmental governance

Posted Date: October 8th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10762308/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

Electronic waste (E-waste) is a rapidly growing environmental challenge in developing countries. This study assessed E-waste generation, management practices, environmental and occupational health risks, and institutional challenges in Gazipur City Corporation, Bangladesh. Using an integrated mixed-methods approach, including Material Flow Analysis (MFA), surveys, stakeholder interviews, and institutional assessment, data were collected from 375 respondents. The city generated 6,245.21 tons of E-waste in 2024 ($2.43 \text{ kg person}^{-1} \text{ year}^{-1}$), with refrigerators, televisions, and microwave ovens as the major sources. Informal recycling dominated E-waste management, while unsafe handling practices increased environmental and occupational risks. Key barriers included inadequate recycling infrastructure, weak policy implementation, and limited institutional capacity. This study provides an integrated framework to support sustainable E-waste management, Extended Producer Responsibility (EPR), and circular economy implementation in Bangladesh and other developing countries.

1. Introduction

Electronic waste (E-waste), also referred to as Waste Electrical and Electronic Equipment (WEEE), has become one of the fastest-growing solid waste streams worldwide due to rapid technological advancement, urbanization, industrialization, increasing consumer demand, digital transformation, and the shortening lifespan of electrical and electronic equipment (EEE) resulting from technological innovation and product obsolescence (Forti, Baldé et al. 2020, Baldé, Kuehr et al. 2024). According to the Global E-waste Monitor 2024, approximately 62 million metric tonnes (Mt) of E-waste were generated globally in 2022, equivalent to an average of 7.8 kg per capita, representing an increase of about 82% since 2010. Global E-waste generation is projected to reach 82 million tonnes by 2030, increasing by approximately 2.6 million tonnes annually, which substantially exceeds the growth of formal collection and recycling infrastructure (Baldé, Kuehr et al. 2024). Although E-waste contains considerable quantities of valuable secondary raw materials, including iron, aluminium, copper, gold, silver, platinum, palladium, cobalt, lithium, and rare earth elements, with an estimated material value exceeding US\$91 billion annually, only 22.3% (13.8 Mt) of global E-waste was formally collected and recycled in 2022. Consequently, approximately 48.2 million tonnes (77.7%) remained undocumented, being improperly stored in households, illegally exported, openly burned, landfilled, or processed through informal recycling systems. These practices result in the loss of recoverable resources, greenhouse gas emissions, soil and water contamination, and the release of hazardous substances such as lead, mercury, cadmium, brominated flame retardants, and persistent organic pollutants, posing serious risks to ecosystems and human health (Forti, Baldé et al. 2020, Baldé, Kuehr et al. 2024).

E-waste represents a highly heterogeneous and complex mixture of valuable recyclable materials and hazardous substances. While discarded electrical and electronic equipment contains recoverable resources such as iron, aluminium, copper, gold, silver, palladium, cobalt, lithium, and rare earth elements, it also contains numerous toxic constituents that pose significant environmental and public health risks when improperly managed (Robinson 2009, Forti, Baldé et al. 2020). Hazardous substances

commonly found in E-waste include heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), hexavalent chromium (Cr⁶⁺), and arsenic (As); brominated flame retardants (BFRs), including polybrominated diphenyl ethers (PBDEs); polychlorinated biphenyls (PCBs); polycyclic aromatic hydrocarbons (PAHs); dioxins and furans; and other persistent organic pollutants (POPs)(Robinson 2009, Sepúlveda, Schluep et al. 2010, Organization 2021). During informal recycling activities such as manual dismantling, open burning of cables, acid leaching of printed circuit boards, and uncontrolled disposal in open dumps or landfills, these hazardous substances are released into the environment through air emissions, wastewater, ash, and contaminated residues. Consequently, toxic pollutants accumulate in soils, surface water, groundwater, sediments, and the atmosphere, where they persist for long periods, bioaccumulate in food chains, and adversely affect ecosystem integrity, biodiversity, and environmental quality(Sepúlveda, Schluep et al. 2010, Perkins, Drisse et al. 2014). Numerous epidemiological and biomonitoring studies have demonstrated that occupational and community exposure to E-waste-derived contaminants is associated with a wide range of adverse health outcomes, including respiratory diseases, chronic obstructive pulmonary disorders, neurological impairment, cognitive deficits, endocrine disruption, thyroid dysfunction, reproductive and developmental abnormalities, kidney and liver dysfunction, cardiovascular diseases, immune system impairment, DNA damage, and increased risks of certain cancers. These health impacts are particularly severe among informal recycling workers, pregnant women, infants, and children because of their greater physiological susceptibility and prolonged exposure to toxic substances(Grant, Goldizen et al. 2013, Organization 2021).

The challenge of E-waste management is particularly severe in developing countries, where rapid urbanization, industrialization, population growth, increasing household incomes, and accelerated digitalization have substantially increased the consumption of electrical and electronic equipment (EEE), while waste management systems have not expanded at the same pace(Kiddee, Naidu et al. 2013, Forti, Baldé et al. 2020). Many low- and middle-income countries lack comprehensive E-waste collection networks, environmentally sound recycling facilities, effective extended producer responsibility (EPR) schemes, and adequate financial and technical resources for managing the rapidly growing volume of discarded electronics(Parajuly, Habib et al. 2017, Baldé, Kuehr et al. 2024). In addition, weak institutional capacity, fragmented policy implementation, limited public awareness, insufficient regulatory enforcement, and inadequate monitoring mechanisms have hindered the development of formal E-waste management systems(Kiddee, Naidu et al. 2013). As a result, a substantial proportion of E-waste is handled by the informal sector, which is estimated to process the majority of discarded electronic products in many developing countries across Asia and Africa(Chi, Streicher-Porte et al. 2011, Forti, Baldé et al. 2020). Informal recycling commonly involves manual dismantling, open burning of insulated wires to recover copper, acid leaching of printed circuit boards to extract precious metals, crude mechanical separation, and uncontrolled dumping or landfilling of residual waste. These practices release toxic heavy metals, persistent organic pollutants (POPs), brominated flame retardants, dioxins, furans, and fine particulate matter into the air, soil, and water, causing widespread environmental contamination and exposing workers and nearby communities to serious health risks(Sepúlveda, Schluep et al. 2010, Chi, Streicher-Porte et al. 2011, Perkins, Drisse et al. 2014). Nevertheless, the

informal recycling sector plays a significant socioeconomic role by generating employment and income for millions of people while recovering valuable secondary raw materials that contribute to resource conservation and the circular economy. However, because these activities generally operate outside environmental regulations, occupational health and safety standards, and social protection frameworks, they often result in unsafe working conditions, inefficient material recovery, and increased environmental and public health risks(Parajuly, Habib et al. 2017, Forti, Baldé et al. 2020).

Bangladesh is undergoing rapid industrialization, urbanization, economic growth, and digital transformation, leading to a substantial increase in the consumption of electrical and electronic equipment (EEE) across households, commercial establishments, educational institutions, healthcare facilities, and industries(Chi, Streicher-Porte et al. 2011, Islam, Abdullah et al. 2016). Consequently, the generation of electronic waste (E-waste) has increased significantly over the past decade, particularly in major metropolitan and industrial regions such as Dhaka, Chattogram, Gazipur, Narayanganj, and Khulna, where high population density, industrial activities, and growing purchasing power accelerate the replacement of electronic devices(Islam, Abdullah et al. 2016, Forti, Baldé et al. 2020). Bangladesh has also emerged as one of the fastest-growing markets for consumer electronics and information and communication technology (ICT) products in South Asia, further contributing to the rapid accumulation of obsolete electrical and electronic equipment(Environment 2022). Recognizing these challenges, the Government of Bangladesh enacted the Hazardous Waste (E-waste) Management Rules, 2021 under the Bangladesh Environment Conservation Act, introducing provisions for environmentally sound collection, transportation, storage, recycling, treatment, disposal, and the implementation of Extended Producer Responsibility (EPR), requiring manufacturers, importers, and producers to take responsibility for post-consumer E-waste management(Environment 2022). Despite this important policy development, effective implementation remains constrained by inadequate collection infrastructure, limited formal recycling facilities, insufficient technical capacity, weak enforcement of environmental regulations, fragmented institutional coordination, financial limitations, and low public awareness regarding proper E-waste disposal(Forti, Baldé et al. 2020, Environment 2022). Consequently, a large proportion of E-waste continues to be managed by the informal sector, including waste collectors, scrap dealers (locally known as Bhangari shops), repair workshops, refurbishers, and unauthorized recyclers. These actors commonly employ environmentally unsafe recycling techniques such as manual dismantling, open burning of insulated wires, and acid leaching of printed circuit boards, resulting in the release of hazardous substances into the environment and posing serious risks to workers, surrounding communities, and ecosystems(Sepúlveda, Schluep et al. 2010, Chi, Streicher-Porte et al. 2011).

Gazipur City Corporation (GCC), one of Bangladesh's fastest-growing industrial and urban centers, represents an important case for evaluating E-waste management challenges. Located adjacent to the capital city of Dhaka, Gazipur has experienced rapid industrialization, urban expansion, and population growth over the past two decades. The city hosts numerous manufacturing industries, including textile, garment, pharmaceutical, electronics, plastic, and engineering industries, as well as commercial establishments, educational institutions, healthcare facilities, and expanding residential communities. These developments have substantially increased the consumption of electrical and electronic

equipment (EEE), resulting in a growing volume of obsolete electronic products and associated E-waste (Masud, Akram et al. 2019, Forti, Baldé et al. 2020). Although several studies have examined E-waste generation and informal recycling in Bangladesh, To the best of our knowledge, previous studies in Bangladesh have not comprehensively quantified material flows while simultaneously assessing household behaviour, commercial practices, institutional capacity, environmental pollution, occupational health risks, and governance challenges in Gazipur City Corporation. This study addresses these research gaps by developing an integrated analytical framework that combines quantitative Material Flow Analysis (MFA) with socio-environmental and policy assessments.

An integrated assessment is essential for understanding the complex interactions among E-waste generation, material flows, stakeholder behaviour, environmental pollution, occupational health risks, institutional capacity, and governance. By combining these dimensions within a single analytical framework, this study enables a comprehensive evaluation of the E-waste management system and identifies critical intervention points that cannot be captured through conventional waste generation or awareness studies alone. The integrated approach also provides a stronger scientific basis for evidence-based policymaking, implementation of Extended Producer Responsibility (EPR), integration of the informal recycling sector into formal waste management systems, and the promotion of circular economy practices in Bangladesh and other rapidly urbanizing developing countries. The proposed integrated analytical framework provides a transferable approach for evaluating urban E-waste management systems and supports evidence-based decision-making for sustainable E-waste governance in rapidly industrializing cities of developing countries.

Therefore, this study aims to (i) quantify E-waste generation in Gazipur City Corporation using Material Flow Analysis; (ii) evaluate household, commercial, institutional, and informal-sector E-waste management practices; (iii) assess environmental pollution and occupational health risks associated with current handling, recycling, and disposal practices; (iv) identify technological, infrastructural, institutional, financial, and regulatory barriers to environmentally sound E-waste management; and (v) propose evidence-based policy recommendations to strengthen formal recycling systems, promote Extended Producer Responsibility (EPR), improve occupational safety, integrate the informal sector into formal waste management systems, and advance circular economy practices in Bangladesh. The findings are expected to provide valuable scientific evidence for policymakers, environmental managers, urban planners, and regulatory authorities seeking to develop sustainable E-waste governance strategies for rapidly urbanizing cities in developing countries.

2. Methodology

2.1 Study Area

The study was conducted in Gazipur City Corporation (GCC), Bangladesh, one of the country's fastest-growing industrial and urban regions (Fig. 1). GCC is located immediately north of Dhaka, between approximately 23°53' and 24°20' N latitude and 90°09' and 90°42' E longitude, and covers an area of

approximately 329.53 km² comprising 57 administrative wards (Corporation 2023). According to the Bangladesh Bureau of Statistics(Statistics 2022), GCC has an estimated population exceeding 2.5 million, making it one of the largest and most densely populated urban centers in Bangladesh. During the past two decades, the city has experienced rapid industrialization, urban expansion, and population growth driven by its strategic location adjacent to Dhaka and its role as a major manufacturing hub(Statistics 2022). Gazipur hosts thousands of industrial establishments, including ready-made garment (RMG), textile, pharmaceutical, electronics, plastic, engineering, food-processing, and light manufacturing industries, together with numerous commercial establishments, educational institutions, healthcare facilities, repair workshops, and informal scrap markets. These activities have substantially increased the consumption of electrical and electronic equipment (EEE), leading to a corresponding increase in the generation of electronic waste(Statistics 2022, Corporation 2023). The city's rapid economic development, high population density, expanding industrial base, and active informal recycling sector make Gazipur an appropriate case study for investigating E-waste generation, management practices, stakeholder behavior, and associated environmental and public health challenges.

The rapid expansion of industrial production, urbanization, population growth, and household electronic consumption has substantially increased the generation of electronic waste (E-waste) in Gazipur City Corporation (GCC). As one of Bangladesh's largest industrial hubs, Gazipur accommodates thousands of manufacturing industries, including ready-made garment (RMG), textile, pharmaceutical, electronics, plastic, engineering, and light manufacturing industries, together with rapidly expanding residential, commercial, educational, and healthcare sectors. These activities have significantly increased the demand for electrical and electronic equipment (EEE), resulting in a growing volume of obsolete electronic products requiring environmentally sound management(Statistics 2022, Corporation 2023). Similar industrial cities in low- and middle-income countries have experienced rapid growth in electronic consumption without corresponding improvements in formal collection, recycling, and disposal infrastructure. Consequently, large quantities of E-waste are processed through informal recycling systems employing manual dismantling, open burning, and acid leaching, which release hazardous pollutants into the environment and expose workers and nearby communities to serious occupational and public health risks(Perkins, Drisse et al. 2014, Forti, Baldé et al. 2020, Baldé, Kuehr et al. 2024). Although Bangladesh has introduced the Hazardous Waste (E-waste) Management Rules, 2021, comprehensive city-level information on E-waste generation, material flows, stakeholder behaviour, recycling practices, institutional capacity, and policy implementation remains limited, particularly for rapidly industrializing cities such as Gazipur. Consequently, Gazipur City Corporation provides an appropriate and policy-relevant case study for evaluating E-waste generation, management practices, and opportunities for improving sustainable E-waste governance in Bangladesh(Masud, Akram et al. 2019, Bangladesh 2021).

2.2 Research Design

A mixed-methods research design integrating quantitative and qualitative approaches was adopted to comprehensively evaluate E-waste generation, management practices, environmental pollution,

occupational health risks, and institutional challenges in Gazipur City Corporation. Mixed-methods research has been widely recommended for environmental management studies because it enables the integration of quantitative measurements with qualitative stakeholder perceptions, thereby improving the reliability and validity of research findings(Creswell and Clark 2017).

The quantitative component focused on estimating E-waste generation, disposal behavior, storage practices, collection mechanisms, and stakeholder participation through structured questionnaire surveys. The qualitative component explored institutional arrangements, governance mechanisms, informal-sector operations, technological limitations, environmental challenges, and policy implementation through semi-structured interviews, key informant interviews (KIIs), and direct field observations. The integration of multiple data sources allowed methodological triangulation, thereby reducing uncertainty and enhancing the robustness of the findings(Creswell and Clark 2017).

2.3 Sampling Design and Participant Selection

The study involved 375 respondents representing major stakeholders across the E-waste management chain in Gazipur City Corporation. Participants were selected using a combination of stratified purposive sampling and snowball sampling.

Stratified purposive sampling was used for household selection to ensure representation of different socioeconomic groups and residential locations within the city. Snowball sampling was adopted for identifying informal E-waste collectors, Bhangari shop owners, repair workshops, dismantlers, and recyclers because no official database exists for these informal actors, a common challenge in informal-sector research(Kiddee, Naidu et al. 2013).

The distribution of respondents is presented in Table 1

Table 1
Distribution of survey respondents by stakeholder category

Stakeholder Category	Number
Households	197
Informal E-waste collectors	48
Bhangari shop owners	43
E-waste businessmen	42
Institutions and companies	26
Regulatory bodies and policymakers	19
Total	375

This sampling strategy enabled representation of all key actors involved in E-waste generation, collection, recycling, and governance within Gazipur.

2.4 Primary Data Collection

Primary data were collected between 2023 and 2024 using structured questionnaires, semi-structured interviews, key informant interviews, and field observations.

2.4.1 Household Survey

Structured questionnaires were administered to 197 households located across different socioeconomic and residential areas of Gazipur City Corporation. Information collected included ownership of electrical and electronic equipment, product lifespan, replacement frequency, storage duration, disposal methods, recycling preferences, and awareness of environmental and health impacts associated with E-waste.

The questionnaire consisted of both closed-ended and open-ended questions. Closed questions generated quantitative data suitable for statistical analysis, whereas open-ended questions provided contextual information regarding household perceptions and disposal behavior.

2.4.2 Informal-sector Survey

Semi-structured interviews were conducted with 133 informal-sector stakeholders, including 48 informal collectors, 43 Bhangari shop owners, and 42 E-waste businessmen.

The interviews investigated:

- a. collection and transportation systems;
- b. repair and refurbishment activities;
- c. dismantling techniques;
- d. material recovery practices;
- e. occupational safety;
- f. economic incentives;
- g. recycling markets; and
- h. operational challenges.

Informal recycling has been recognized as the dominant E-waste management pathway in many developing countries, making stakeholder interviews essential for understanding material flows and environmental risks(Chi, Streicher-Porte et al. 2011, Awasthi, Li et al. 2019).

2.4.3 Institutional Survey

Twenty-six institutions and companies were surveyed to evaluate E-waste generation, storage, disposal mechanisms, recycling arrangements, institutional policies, and waste management practices.

The survey also examined the availability of collection systems, recycling facilities, training programs, environmental monitoring, and compliance with Bangladesh's Hazardous Waste (E-waste) Management Rules 2021 (Bangladesh 2021).

2.4.4 Key Informant Interviews

Key Informant Interviews (KIIs) were conducted with 19 representatives from Gazipur City Corporation, the Department of Environment (DoE), NGOs, environmental experts, and policymakers.

Discussions focused on:

- a. current E-waste policies;
- b. institutional responsibilities;
- c. regulatory enforcement;
- d. municipal waste management;
- e. Extended Producer Responsibility (EPR);
- f. technological capacity;
- g. public awareness; and
- h. future policy interventions.

2.4.5 Field Observation

Extensive field observations were carried out at municipal dumping sites, informal recycling workshops, dismantling yards, repair centers, scrap markets (Bhangari shops), and temporary storage facilities throughout Gazipur.

Observation checklists were developed to record:

- a. waste segregation;
- b. dismantling techniques;
- c. recycling activities;
- d. hazardous waste handling;
- e. open burning;
- f. environmental pollution;
- g. use of personal protective equipment (PPE); and
- h. occupational safety conditions.

Field observations were used to validate questionnaire responses and interview findings.

2.5 Secondary Data Collection

Secondary data were collected from peer-reviewed journal articles, government reports, Gazipur City Corporation publications, Bangladesh Bureau of Statistics (BBS), Department of Environment reports, the Global E-waste Monitor (2020 and 2024), policy documents, and international databases.

These sources were used to compare local findings with national and global E-waste trends and to support estimates of E-waste generation and policy analysis.

2.6 Material Flow Analysis (MFA)

Material Flow Analysis (MFA) was applied to quantify E-waste generation and evaluate material flows within Gazipur City Corporation. MFA is a standardized analytical approach used to quantify the movement and accumulation of materials within defined system boundaries and has been widely applied in waste management studies (Brunner and Rechberger 2016).

The system boundary included households, commercial establishments, industries, educational institutions, healthcare facilities, repair workshops, informal collectors, Bhangari shops, recyclers, and disposal sites.

The E-waste management chain was mapped as:

Generation → Collection → Storage → Repair → Refurbishment → Dismantling → Recycling → Final Disposal

Annual E-waste generation was estimated using ownership rates, product lifespan, replacement frequency, and disposal behavior collected during household surveys.

2.7 Assessment of E-waste Management Practices

The performance of existing E-waste management systems was evaluated using environmental, economic, institutional, and occupational health indicators.

The assessment considered:

- a. E-waste generation and storage;
- b. collection efficiency;
- c. transportation;
- d. repair and refurbishment;
- e. recycling and resource recovery;
- f. occupational health and safety;
- g. environmental pollution;
- h. institutional capacity;
- i. public awareness;
- j. technological readiness; and
- k. policy implementation.

Evaluation criteria were adapted from internationally recognized E-waste management frameworks and circular economy principles (Kiddee, Naidu et al. 2013, Parajuly, Habib et al. 2017).

2.8 Statistical Analysis

Questionnaire responses were coded, cleaned, and analyzed using IBM SPSS Statistics (Version XX; IBM Corp., Armonk, NY, USA) and Microsoft Excel 365 (Microsoft Corporation, Redmond, WA, USA). Descriptive statistical techniques, including frequencies, percentages, means, standard deviations, and cross-tabulations, were employed to summarize respondents' socio-demographic characteristics, E-waste generation, disposal practices, stakeholder behavior, occupational health and safety conditions, environmental awareness, and institutional capacity. Where appropriate, cross-tabulations were used to examine relationships among key variables and identify patterns in E-waste management practices.

Qualitative data obtained from semi-structured interviews were transcribed verbatim and analyzed using thematic analysis following the six-phase framework proposed by (Braun and Clarke 2006), including data familiarization, initial code generation, theme identification, theme review, theme definition and naming, and report preparation. Data from household questionnaires, stakeholder interviews, and field observations were subsequently triangulated to enhance the credibility, reliability, and validity of the findings by comparing evidence obtained from multiple data sources (Creswell and Clark 2017, Denzin 2017).

2.9 Ethical Considerations

Participation in this study was voluntary. All participants were informed about the objectives and procedures of the study before data collection, and verbal informed consent was obtained from each participant. Participants were informed that their responses would be treated confidentially and used solely for research purposes. No personally identifying information was disclosed in the analysis or reporting of the findings. The study was conducted in accordance with the research ethics guidelines of the Institute of Water and Environment, Dhaka University of Engineering & Technology (DUET), Gazipur, Bangladesh. Prior to the commencement of data collection, the study received ethical approval from the Committee for Advanced Studies and Research (CASR), Dhaka University of Engineering & Technology (DUET), Gazipur, Bangladesh. All research procedures were conducted in accordance with the ethical standards and guidelines approved by the institution.

3. Results and Discussion

3.1 E-waste Generation and Household Management Practices

The study estimated that approximately 6,245.21 tons of electronic waste (E-waste) were generated in Gazipur City Corporation (GCC) in 2024, corresponding to a per capita generation rate of 2.43 kg person⁻¹ year⁻¹. This finding indicates a rapidly expanding E-waste stream driven by increasing household ownership of electrical and electronic equipment (EEE), rapid urbanization, industrial development, rising household incomes, and the accelerated replacement of electronic products. Although the estimated per capita generation rate is considerably lower than the global average of approximately 7.8 kg person⁻¹ reported for 2022, it is comparable to estimates reported for several low-

and middle-income countries in South Asia and other developing regions, where lower income levels, longer product lifespans, extensive repair and reuse practices, and relatively low formal collection rates reduce per capita E-waste generation compared with high-income economies (Forti, Baldé et al. 2020, Baldé, Kuehr et al. 2024). The relatively low per capita generation observed in GCC may also reflect the widespread reuse, repair, refurbishment, and resale of electrical and electronic equipment through informal markets before final disposal, delaying their entry into the waste stream (Kiddee, Naidu et al. 2013, Masud, Akram et al. 2019). Household E-waste was dominated by refrigerators (42.05%), followed by televisions (19.44%) and microwave ovens (9.26%), indicating that large household appliances constitute the principal contributors to residential E-waste generation in the study area. The predominance of these appliances is likely associated with increasing household electrification, improvements in living standards, changing consumer preferences, and the replacement of older appliances with newer, more energy-efficient models. Similar trends have been reported in other developing countries, where large household appliances account for a substantial proportion of household E-waste due to their high ownership rates, long service lives, and considerable material weight (Forti, Baldé et al. 2020, Baldé, Kuehr et al. 2024).

Most households acquired electronic products from local electrical shops (61.7%) and retail outlets (31.6%), whereas purchases from certified recyclers or refurbished-product suppliers were negligible. This finding suggests that circular economy practices remain poorly established within the formal market.

Household storage of obsolete electronic products was common. Approximately 57.9% of respondents stored less than 10 kg of E-waste annually, while nearly 58% retained obsolete electronic products for future sale because of their residual economic value. Selling discarded electronics to informal collectors represented the most common disposal pathway (48.7%), followed by long-term household storage (28.9%).

Despite the economic benefits associated with the resale and recovery of valuable materials, environmentally unsound E-waste disposal practices remain widespread in Gazipur City Corporation. Approximately 12.2% of surveyed households reported disposing of E-waste together with municipal solid waste, while 3.6% practiced open burning of electronic components. These disposal methods are environmentally hazardous because they can release toxic heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), and hexavalent chromium (Cr^{6+}), together with brominated flame retardants (BFRs), dioxins, furans, and other persistent organic pollutants (POPs) into the surrounding environment. Once released, these contaminants can accumulate in soils, groundwater, surface water, sediments, and the atmosphere, posing long-term ecological risks and adverse human health effects through inhalation, ingestion, and dermal exposure (Robinson 2009, Sepúlveda, Schluep et al. 2010). The open burning of electrical cables and plastic casings is particularly concerning because it generates toxic emissions, including polybrominated dibenzo-p-dioxins and dibenzofurans, while the disposal of E-waste in municipal landfills facilitates the leaching of heavy metals into surrounding soils and groundwater (Perkins, Drisse et al. 2014, Organization 2021). Similar household disposal patterns have

been reported across many low- and middle-income countries, where inadequate formal collection systems, limited recycling infrastructure, weak regulatory enforcement, and low public awareness encourage households to store obsolete electronic products, discard them with municipal solid waste, or transfer them to informal collectors and scrap dealers rather than authorized recycling facilities (Kiddee, Naidu et al. 2013, Parajuly, Habib et al. 2017, Baldé, Kuehr et al. 2024). These findings highlight the urgent need to strengthen household E-waste collection systems, expand formal recycling infrastructure, improve public awareness, and effectively implement Extended Producer Responsibility (EPR) to reduce environmentally unsafe disposal practices.

3.2 Commercial and Institutional E-waste Management Practices

Commercial establishments exhibited disposal behaviors comparable to households but generated relatively larger volumes of obsolete electronic equipment because of shorter replacement cycles and continuous technological upgrading. Approximately 45.2% of businesses sold discarded electronics to informal collectors or scrap dealers, while 23.8% reported open burning of insulated wires and electronic components to recover valuable metals. Such practices contribute to the emission of toxic pollutants including dioxins, furans, particulate matter, and heavy metals, thereby increasing environmental pollution and occupational health risks (Grant, Goldizen et al. 2013).

Institutions and companies demonstrated comparatively better management practices. Approximately 69.2% sold obsolete electronic products through resale channels, whereas 11.5% reported limited recycling initiatives. Nevertheless, some institutions continued environmentally unsafe disposal practices such as dumping obsolete electronics together with municipal waste or burning electronic components. These findings indicate that institutional awareness alone is insufficient without accessible formal recycling facilities and effective regulatory oversight.

The limited participation of certified recycling companies demonstrates that formal E-waste management infrastructure in Gazipur remains underdeveloped. Consequently, valuable secondary resources continue to flow into informal recycling networks rather than environmentally sound recycling facilities.

3.3 Dominance of the Informal Recycling Sector

The results demonstrate that the informal sector constitutes the backbone of E-waste management in Gazipur City Corporation. Informal collectors, itinerant buyers, Bhangari shops, repair workshops, dismantlers, and small-scale recyclers dominate the collection, transportation, refurbishment, dismantling, and material recovery processes.

Approximately **39%** of E-waste originated from informal collection networks, while repair and refurbishment activities accounted for nearly 38% of business operations. Repairing and refurbishing obsolete electronic products extends product lifespan and contributes positively to resource efficiency and circular economy objectives. However, downstream dismantling and material recovery largely

depend on primitive techniques including manual dismantling, cable burning, and informal metal extraction.

Open burning of insulated cables and manual dismantling release heavy metals, polycyclic aromatic hydrocarbons (PAHs), brominated flame retardants, and other toxic compounds into the surrounding environment (Sepúlveda, Schluep et al. 2010). Bhangari shops function as important intermediaries by purchasing, sorting, repairing, and reselling obsolete electronics before transferring residual materials to dismantlers and recyclers. Nevertheless, these activities remain largely unregulated and operate without environmental monitoring or occupational safety standards.

Comparable informal recycling systems have been documented in India, China, Ghana, Nigeria, and Pakistan, where the informal sector simultaneously contributes to employment generation and environmental degradation (Widmer, Oswald-Krapf et al. 2005, Chi, Streicher-Porte et al. 2011, Awasthi, Li et al. 2019). Integrating informal collectors into formal recycling systems through training, certification, financial incentives, and Extended Producer Responsibility (EPR) schemes could substantially improve both resource recovery and environmental performance.

3.4 Occupational Health Risks Associated with Informal Recycling

Occupational health conditions among informal E-waste workers were found to be critically inadequate. Only 7% of respondents reported using personal protective equipment (PPE), whereas approximately 60% performed dismantling and recycling activities without any protective measures. Similarly low levels of PPE use have been reported among informal E-waste workers in China, India, Ghana, and Nigeria, where inadequate occupational safety training, limited regulatory enforcement, and financial constraints contribute to unsafe recycling practices (Sepúlveda, Schluep et al. 2010, Grant, Goldizen et al. 2013, Awasthi, Li et al. 2019). The remaining respondents demonstrated only limited awareness of occupational safety practices.

Workers engaged in informal E-waste recycling in Gazipur City Corporation frequently reported respiratory illness, persistent cough, chest pain, skin irritation, burns, musculoskeletal disorders, eye irritation, cuts, and other physical injuries associated with manual dismantling, open burning, and handling of discarded electronic components. These occupational health problems are largely attributable to prolonged exposure to airborne particulate matter, toxic metal dust, combustion products, acid fumes, and hazardous chemicals released during dismantling, cable burning, and crude material recovery processes. Continuous exposure to heavy metals such as lead (Pb), mercury (Hg), cadmium (Cd), and arsenic (As), together with brominated flame retardants (BFRs), dioxins, furans, and persistent organic pollutants (POPs), has been associated with neurological impairment, reduced cognitive function, kidney and liver dysfunction, endocrine disruption, reproductive abnormalities, impaired immune function, cardiovascular diseases, adverse birth outcomes, and an increased risk of certain cancers (Grant, Goldizen et al. 2013, Perkins, Drisse et al. 2014, Organization 2021). These findings are consistent with previous studies conducted in major informal E-waste recycling areas in China, Ghana,

India, and Nigeria, where workers and nearby residents exhibited elevated concentrations of heavy metals and persistent organic pollutants in blood, urine, hair, breast milk, and surrounding environmental media, reflecting chronic occupational and environmental exposure (Sepúlveda, Schluep et al. 2010, Grant, Goldizen et al. 2013, Perkins, Drisse et al. 2014). The health risks are further exacerbated by the widespread absence of personal protective equipment (PPE), inadequate occupational health and safety training, limited awareness of hazardous material handling, lack of routine medical surveillance, poor workplace ventilation, and weak enforcement of occupational health and environmental regulations. These findings emphasize the urgent need for formalization of the informal recycling sector, implementation of occupational health monitoring programs, provision of appropriate protective equipment, and stricter enforcement of environmental and workplace safety standards to reduce health risks among E-waste recycling workers (Forti, Baldé et al. 2020, Organization 2021).

3.5 Institutional Capacity and Infrastructure Constraints

The institutional assessment revealed substantial weaknesses in the formal E-waste management system of Gazipur City Corporation. More than 84% of surveyed institutions reported the absence of formal E-waste training programmes for employees, while 92.3% indicated that no accredited monitoring, auditing, or certification body currently oversees E-waste management practices. These findings suggest that institutional capacity for environmentally sound E-waste management remains inadequate despite the increasing generation of discarded electrical and electronic equipment. Respondents identified inadequate recycling infrastructure (39%), insufficient treatment and collection facilities (22%), financial constraints (20%), weak policy implementation, fragmented institutional responsibilities, limited technical expertise, and poor coordination among relevant government agencies as the principal barriers to effective E-waste management. Similar institutional challenges have been widely documented in developing countries, where insufficient investment in collection systems, recycling facilities, regulatory enforcement, and human resource development has constrained the establishment of sustainable E-waste management systems despite increasing waste generation (Kiddee, Naidu et al. 2013, Forti, Baldé et al. 2020, Baldé, Kuehr et al. 2024). Furthermore, inadequate public awareness, the dominance of informal recycling networks, limited implementation of Extended Producer Responsibility (EPR), and weak stakeholder collaboration continue to undermine the transition towards a circular economy and environmentally sound E-waste management (Parajuly, Habib et al. 2017, Baldé, Kuehr et al. 2024). Although Bangladesh enacted the Hazardous Waste (E-waste) Management Rules, 2021, which establish legal provisions for E-waste collection, transportation, recycling, treatment, disposal, and producer responsibility, effective implementation remains constrained by limited institutional capacity, inadequate technical expertise, insufficient financial resources, poor monitoring systems, and weak enforcement mechanisms. Comparable governance challenges have been reported across many low- and middle-income countries, where regulatory frameworks exist but practical implementation remains limited because of institutional fragmentation, inadequate funding, and insufficient administrative capacity (Kiddee, Naidu et al. 2013, Baldé, Kuehr et al. 2024). Strengthening institutional coordination, expanding formal recycling infrastructure, enhancing technical

capacity, improving compliance monitoring, and fully implementing Extended Producer Responsibility (EPR) are therefore essential for achieving sustainable E-waste management in Bangladesh.

3.6 Public Awareness and Environmental Implications

Public awareness regarding the environmental and health impacts of E-waste was generally low. Nearly 60% of respondents lacked adequate knowledge of hazardous substances contained in electronic products or the environmental consequences of improper disposal. Comparable levels of low public awareness have been reported in other developing countries, where insufficient environmental education and limited access to formal recycling services contribute to improper disposal practices (Kiddee, Naidu et al. 2013, Awasthi, Li et al. 2019).

Improper dismantling, open burning, indiscriminate dumping, and disposal together with municipal solid waste facilitate the release of toxic contaminants into soil, surface water, groundwater, and the atmosphere. Heavy metals and brominated flame retardants can persist in environmental media for extended periods and may enter food chains through bioaccumulation, posing significant risks to ecosystem health and human well-being (Robinson 2009, Forti, Baldé et al. 2020).

Considering Gazipur's continuing industrial expansion and population growth, E-waste generation is expected to increase substantially during the coming decades. Without timely investments in formal recycling infrastructure, implementation of Extended Producer Responsibility (EPR), technological modernization, public awareness programmes, and stronger regulatory enforcement, environmental pollution and occupational health risks are likely to intensify. These findings emphasize the urgent need to transition from the current informal recycling system towards an integrated circular economy framework that promotes resource recovery while minimizing environmental contamination and protecting public health (Parajuly, Habib et al. 2017, Baldé, Kuehr et al. 2024).

4 Conclusion

This study provides a comprehensive assessment of electronic waste (E-waste) management, environmental pollution, and associated health risks in Gazipur City Corporation (GCC), Bangladesh. The findings demonstrate that the current E-waste management system is predominantly dependent on informal collection, repair, dismantling, and recycling activities, with limited involvement of formal recycling infrastructure and inadequate regulatory oversight. Approximately 6,245.21 tons of E-waste were generated in GCC in 2024, corresponding to a per capita generation rate of 2.43 kg person⁻¹ year⁻¹, indicating a rapidly increasing waste stream driven by urbanization, industrial expansion, and growing consumption of electrical and electronic equipment. The study revealed that refrigerators, televisions, and microwave ovens constitute the largest proportion of household E-waste, while economic incentives strongly influence disposal behavior, with the majority of households, commercial establishments, and institutions selling obsolete electronic products to informal collectors. Despite its significant contribution to resource recovery, recycling, and employment generation, the informal sector operates predominantly through environmentally unsafe practices, including manual dismantling, open burning,

and improper disposal of hazardous components, owing to limited formal recycling infrastructure and weak regulatory oversight. These practices release toxic substances such as heavy metals and brominated flame retardants into the environment, increasing the risks of soil, water, and air contamination as well as adverse human health effects. The assessment further identified significant occupational health concerns among informal E-waste workers. Extremely low use of personal protective equipment, combined with prolonged exposure to hazardous substances, places workers at increased risk of respiratory diseases, skin disorders, burns, musculoskeletal injuries, and other chronic health problems. In addition, weak institutional capacity, insufficient recycling infrastructure, limited technical expertise, inadequate policy enforcement, and low public awareness collectively hinder the development of environmentally sound E-waste management systems in Gazipur.

This study provides one of the most comprehensive assessments of electronic waste management in Gazipur City Corporation by integrating estimates of E-waste generation, disposal and recycling practices, environmental pollution pathways, occupational health risks, and institutional challenges within a single analytical framework. Unlike previous studies that have primarily focused on individual aspects of E-waste, this research provides a holistic evaluation of the interactions between waste generation, informal recycling activities, environmental contamination, public health, and policy implementation. By establishing baseline data on E-waste generation rates, management practices, and associated environmental and health impacts, this study provides valuable scientific evidence to support the development of evidence-based policies, sustainable recycling strategies, and future research on E-waste management in Bangladesh.

These findings highlight the urgent need for an integrated and sustainable E-waste management framework that balances environmental protection, resource recovery, and public health. To achieve this goal, priority actions should include the rapid establishment of certified E-waste collection centres and environmentally compliant recycling facilities across Gazipur City Corporation, effective implementation of Extended Producer Responsibility (EPR) to ensure producer accountability throughout the product life cycle, modernization of recycling technologies to minimize hazardous emissions and maximize resource recovery, and strengthened regulatory monitoring and enforcement to prevent illegal dumping and unsafe recycling practices. Equally important is the formal integration of informal collectors and recyclers into the regulated waste management system through capacity building, technical training, certification, occupational health and safety programmes, financial incentives, and social protection measures. Such an integrated approach would enhance collection efficiency, improve recycling performance, increase recovery of valuable secondary materials, reduce environmental pollution, protect workers and surrounding communities from hazardous exposures, and accelerate the transition toward a circular economy in Bangladesh. The findings of this study provide robust scientific evidence to support policymakers, Gazipur City Corporation, the Department of Environment (DoE), producers, recycling industries, and other relevant stakeholders in developing and implementing science-based E-waste management policies that strengthen regulatory compliance, promote environmentally sound recycling, enhance resource recovery, protect public health, and facilitate the transition toward a sustainable circular economy in Bangladesh.

Furthermore, large-scale public awareness campaigns, stakeholder collaboration, and investment in environmentally sound recycling technologies are essential to reduce hazardous emissions and promote responsible disposal of end-of-life electronic products. Adoption of circular economy principles that prioritize waste prevention, product reuse, repair, refurbishment, and material recovery would further enhance resource efficiency and reduce environmental burdens.

Although this study provides valuable baseline information for urban E-waste management in Bangladesh, it was limited to Gazipur City Corporation and primarily relied on cross-sectional survey data. Future research should quantify contaminant concentrations in environmental media (soil, water, air, and sediments), assess heavy metal exposure among informal recycling workers through biomonitoring, apply life cycle assessment (LCA) and material flow analysis (MFA) to evaluate resource recovery efficiency, and investigate the long-term environmental and socioeconomic impacts of implementing formal E-waste management systems. Such research would provide stronger scientific evidence to support national E-waste policies and contribute to achieving the Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action).

Overall, transitioning from an informal and fragmented E-waste management system toward an integrated circular economy supported by robust governance, technological innovation, stakeholder collaboration, evidence-based policymaking, and sustained investment in environmentally sound infrastructure represents a critical pathway for reducing environmental pollution, protecting public health, maximizing the recovery of valuable secondary resources, strengthening resource efficiency, and achieving sustainable urban development in Bangladesh. The successful implementation of this integrated approach will not only address the growing challenges of E-waste management in Gazipur City Corporation but also provide a scalable model for other rapidly urbanizing cities in Bangladesh and comparable developing countries facing similar environmental and public health challenges.

Declarations

Ethics Approval and Consent to Participate

The study received ethical approval from the Committee for Advanced Studies and Research (CASR), Dhaka University of Engineering & Technology (DUET), Gazipur, Bangladesh, prior to the commencement of data collection. Participation in the study was voluntary. All participants were informed about the objectives and procedures of the study, and verbal informed consent was obtained from all participants before data collection. The confidentiality and anonymity of all participants were maintained throughout the study.

Consent for Publication

Not applicable.

Competing Interests

The authors declare that they have no competing interests.

Funding

The authors received no specific funding for this study.

Data Availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Clinical trial number: not applicable

Declaration of Generative AI and AI-Assisted Technologies

During the preparation of this manuscript, the authors did not use generative artificial intelligence or AI-assisted technologies to generate the scientific content, analyze the data, or draw conclusions. Any language editing assistance, if applicable, was used only to improve grammar and readability, and the authors take full responsibility for the content of the manuscript.

Data Availability / Dataset Link for Secondary Source

1. Gazipur City Corporation (GCC)

<https://gcc.gov.bd/pages/static-pages/6922ddc3933eb65569e16266>

2. Department of Environment (DoE), Bangladesh

<https://doe.gov.bd/pages/static-pages/6922dfe3933eb65569e24824>

3. Bangladesh Bureau of Statistics (BBS)

<https://bbs.gov.bd/pages/static-pages/6922dcc8933eb65569e12081>

References

1. Awasthi, A. K., J. Li, L. Koh and O. A. Ogunseitan (2019). "Circular economy and electronic waste." *Nature Electronics* **2**(3): 86–89.
2. Baldé, C. P., R. Kuehr, T. Yamamoto, R. McDonald, E. D'Angelo, S. Althaf, G. Bel, O. Deubzer, E. Fernandez-Cubillo and V. Forti (2024). *Global e-waste monitor 2024*, International telecommunication union (ITU) and United Nations institute for
3. Bangladesh, G. o. t. P. s. R. o. (2021). *Hazardous Waste (E-waste) Management Rules, 2021*. Dhaka, Bangladesh, Ministry of Environment, Forest and Climate Change.
4. Braun, V. and V. Clarke (2006). "Using thematic analysis in psychology." *Qualitative research in psychology* **3**(2): 77–101.
5. Brunner, P. H. and H. Rechberger (2016). *Handbook of material flow analysis: For environmental, resource, and waste engineers*, CRC press.

6. Chi, X., M. Streicher-Porte, M. Y. Wang and M. A. Reuter (2011). "Informal electronic waste recycling: A sector review with special focus on China." *Waste management* 31(4): 731–742.
7. Corporation, G. C. (2023). "Gazipur City Corporation." from <https://gcc.gov.bd/>.
8. Creswell, J. W. and V. L. P. Clark (2017). *Designing and conducting mixed methods research*, Sage publications.
9. Denzin, N. K. (2017). *The research act: A theoretical introduction to sociological methods*, Routledge.
10. Environment, D. o. (2022). *Assessment of Generation of E-waste, Its Impacts on Environment and Resource Recovery Potential in Bangladesh*. Dhaka, Bangladesh, Department of Environment.
11. Forti, V., C. P. Baldé, R. Kuehr and G. Bel (2020). "The global e-waste monitor 2020." United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Rotterdam **120**: 14.
12. Grant, K., F. C. Goldizen, P. D. Sly, M.-N. Brune, M. Neira, M. van den Berg and R. E. Norman (2013). "Health consequences of exposure to e-waste: a systematic review." *The lancet global health* 1(6): e350–e361.
13. Islam, M. T., A. B. Abdullah, S. Shahir, M. A. Kalam, H. H. Masjuki, R. Shumon and M. H. Rashid (2016). "A public survey on knowledge, awareness, attitude and willingness to pay for WEEE management: Case study in Bangladesh." *Journal of cleaner production* **137**: 728–740.
14. Kiddee, P., R. Naidu and M. H. Wong (2013). "Electronic waste management approaches: An overview." *Waste management* **33**(5): 1237–1250.
15. Masud, M. H., W. Akram, A. Ahmed, A. A. Ananno, M. Mourshed, M. Hasan and M. U. H. Joardder (2019). "Towards the effective E-waste management in Bangladesh: a review." *Environmental Science and Pollution Research* **26**(2): 1250–1276.
16. Organization, W. H. (2021). *Children and digital dumpsites: e-waste exposure and child health*, World Health Organization.
17. Parajuly, K., K. Habib and G. Liu (2017). "Waste electrical and electronic equipment (WEEE) in Denmark: Flows, quantities and management." *Resources, Conservation and Recycling* **123**: 85–92.
18. Perkins, D. N., M.-N. B. Drisse, T. Nxele and P. D. Sly (2014). "E-waste: a global hazard." *Annals of global health* **80**(4): 286–295.
19. Robinson, B. H. (2009). "E-waste: an assessment of global production and environmental impacts." *Science of the total environment* 408(2): 183–191.
20. Sepúlveda, A., M. Schluep, F. G. Renaud, M. Streicher, R. Kuehr, C. Hagelüken and A. C. Gerecke (2010). "A review of the environmental fate and effects of hazardous substances released from electrical and electronic equipments during recycling: Examples from China and India." *Environmental impact assessment review* 30(1): 28–41.
21. Statistics, B. B. o. (2022). *Population and Housing Census 2022*. Dhaka, Bangladesh, Bangladesh Bureau of Statistics.

22. Widmer, R., H. Oswald-Krapf, D. Sinha-Khetriwal, M. Schnellmann and H. Böni (2005). "Global perspectives on e-waste." *Environmental impact assessment review* **25**(5): 436–458.

Figures

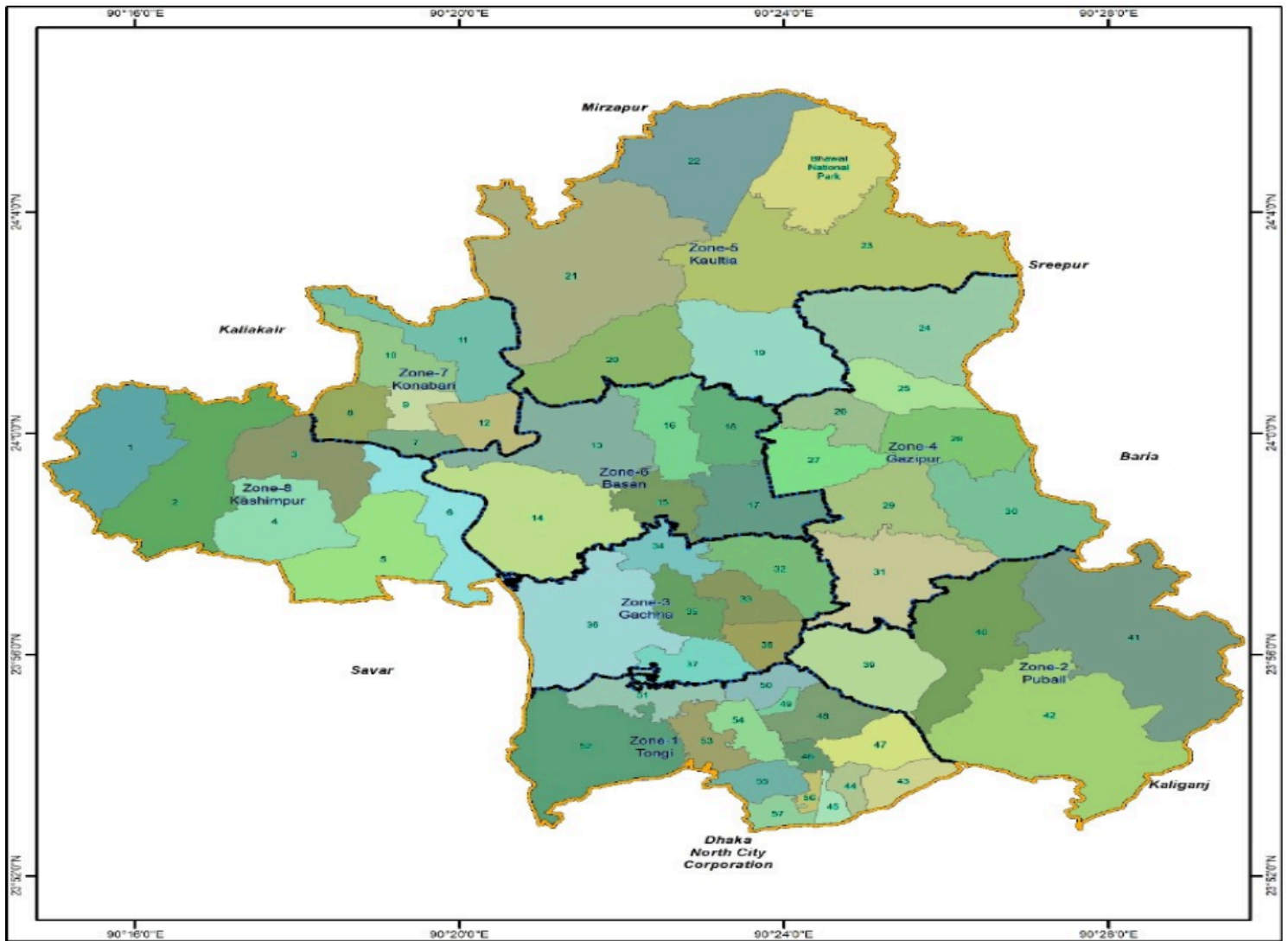


Figure 1

Map of Eight Different Zones in GCC (Source: CRTS, Department of Civil Engineering, DUET, Gazipur)

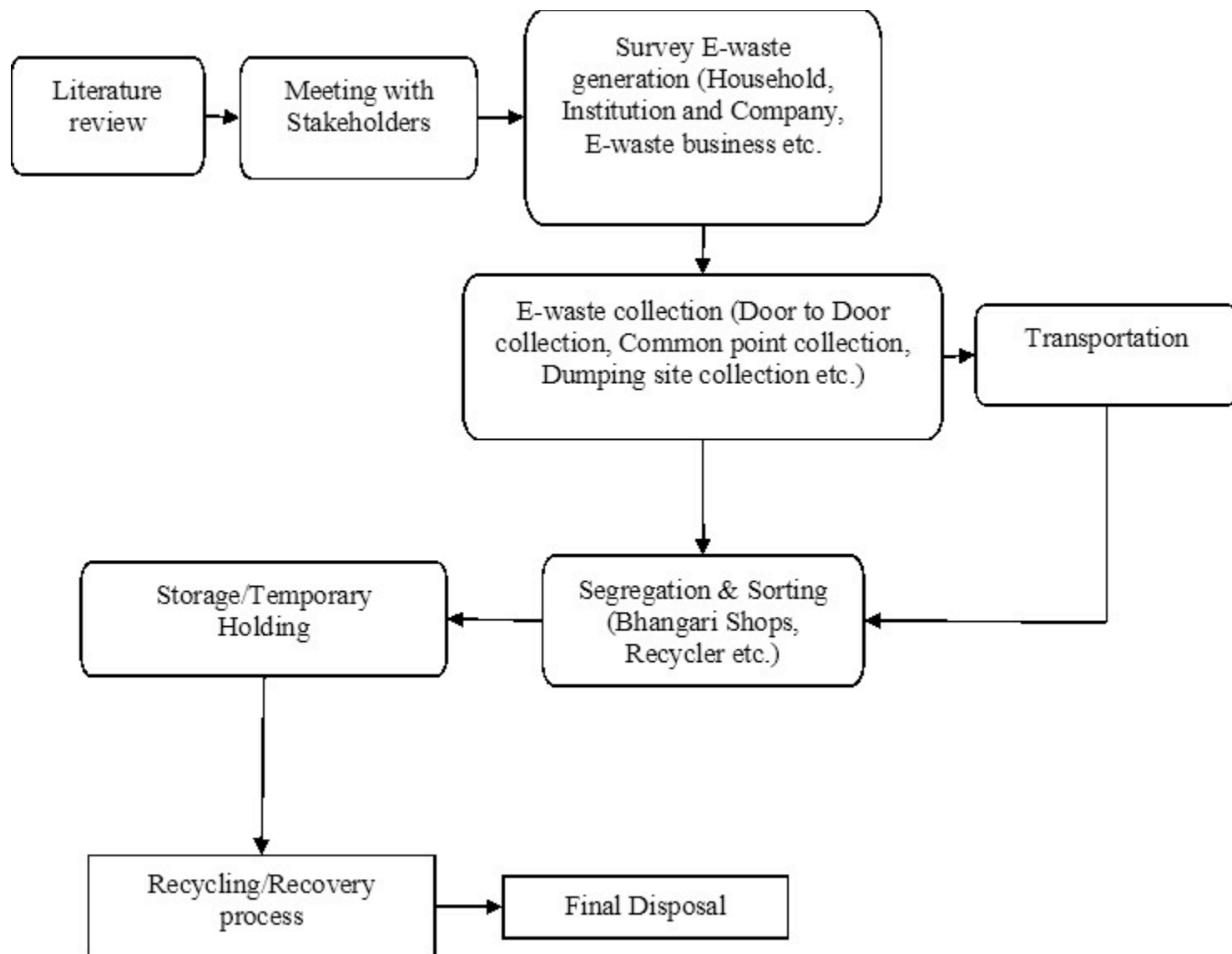


Figure 2

Assessment of the E-waste Management practices in Gazipur City Corporation