Towards Inclusive E-Waste Management: Linking Informal and Formal Systems

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Abstract

In the context of rapid urbanization and increasing technological adoption, the generation of electronic waste (e-waste) has become a pressing environmental and public health challenge. Waste Electrical and Electronic Equipment (WEEE) is among the most hazardous forms of solid waste, requiring specialized management and disposal mechanisms. In India, however, only 3% of total e-waste is processed through authorized recycling facilities, with the vast majority handled by the informal sector in cities like Delhi, Mumbai, and Bangalore. Informal e-waste recycling practices—such as open dismantling, lack of protective gear, and burning of non-recyclable materials—pose severe health risks and contribute significantly to environmental degradation.

Despite these risks, the informal sector plays a crucial socio-economic role by providing livelihoods to thousands and indirectly supporting formal municipal waste systems. Recognizing this, the study explores the existing dynamics of e-waste management in India, focusing on the roles, challenges, and interdependencies between the formal and informal sectors. Primary field surveys conducted among consumers, informal workers, and small-to-medium enterprises (SMEs) provide insights into awareness levels and current disposal behaviors.

The study further highlights how **geospatial technologies** can act as a bridge between the informal and formal systems of e-waste management. Spatial analysis using **enterprise-GIS** techniques was employed to map e-waste generation patterns, reveal one-to-many and many-to-many relationships in waste flows, and identify optimal locations for formal recycling facilities. The integration of geospatial tools offers a strategic approach to planning, monitoring, and improving coordination between sectors, enhancing both environmental sustainability and economic efficiency in e-waste management.

1. Introduction

1.1 Background and Context

"Electronic waste" includes abandoned computers, office electronic equipment, entertainment device electronics, mobile phones, television sets, and refrigerators. This definition comprises used electronics intended for reuse, resale, salvage, recycling, or disposal.

The term "e-waste" refers to practically all types of electrical and electronic equipment (EEE) that have or may enter the waste stream. Although e-waste is a broad term, it can refer to TVs, computers, mobile phones, white goods (such as refrigerators, washing machines, and dryers), home entertainment and stereo systems, toys, toasters, kettles, and almost any household or business item that operates on an electric or electromagnetic principle.

E-waste is increasing exponentially because the marketplaces in which these products are created are expanding rapidly as many parts of the world pass the 'Digital Divide'. Rapid product innovation and replacement, particularly in ICT and office equipment, as well as the transition from analogue to digital technology, such as flat-screen TVs and monitors, are driving the growth. Furthermore, economies of scale have led to lower prices for many electronic goods, resulting in greater global demand for numerous products that eventually end up as e-waste.

1.2 Why E-Waste is different from general Municipal Waste?

Because of its complex composition of valuable and hazardous elements, e-waste must be processed using specialised, typically "high-tech" procedures that maximise resource recovery while minimising potential human or environmental harm. Unfortunately, the employment of these specialised processes is uncommon, with majority of the world's e-waste travelling long distances, primarily to developing countries, where primitive procedures are frequently employed to extract precious materials or recover parts for reuse. These "backyard" tactics endanger both workers who are not adequately protected and the local environment.

1.3 E-Waste – A Global Challenge

In conclusion, the e-waste problem is a global concern due to the nature of trash creation and disposal in a globalised world. Although it is difficult to determine worldwide e-waste levels, we do know that vast amounts wind up in regions with extremely basic processing. This raises questions about resource efficiency, as well as acute problems of the humans and environment.

The e-waste problem involves a long and often convoluted chain of events, beginning with a concept for a new product, followed by its production, purchase, and eventual disposal by the end user. Education is the first step in solving the e-waste problem, and knowledge leads to lifestyle changes.

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1.4 Perspective of E- Waste in India

India's electronic waste (e-waste) crisis is escalating rapidly. The country has emerged as the world's third-largest generator of e-waste, with a staggering 151.03% increase in just six years, from 7.08 lakh metric tonnes in 2017-18 to 17.78 lakh metric tonnes in 2023-24. This surge is driven by the growing adoption of electronic devices, resulting in significant environmental and health concerns. (SHARMA, 2025)

In today's scenario, to cater all services in a living habitat is very necessary part to fulfil the need of the each and every individual to live a comfortable level of their living standard. Whether the consideration is for urban areas or rural areas, all sort of services needs to be address by the authority of the particular place catering services to the people. The nagarpalika, Corporation body or urban development Authority is almost trying to cater all possible services to their concern cities and villages, all those areas who are headed with the authority. These services may include transportation service, water supply, drainage facility, solid waste facility, etc. If these services are not managed properly or not delivered successfully to the users, than this may leads to the disturbance in the whole system of the living habitant. Only one day if any of the above mentioned services are not maintained or not managed than these may leads to the disturbance of the comfortable living of all the individuals.

Similarly if the waste is not managed properly or not attended in an appropriate way than it can be harmful for the society as well as for the environment. These waste can be any such as construction waste, biomedical waste, dead animal waste, holistic waste, food waste, municipal solid waste, electronic waste. In all these types of waste, there are many substances present which are harmful for the living habitats as well as for the environment, if they are not managed properly or in the right way they should be treated.

Out of all this waste (Electronic Waste) E-waste is one of the hazardous waste comparing with other types of waste, which is globally a challenge to handle the emerging issues with the E-waste management in today's scenario in India. Developing countries are facing lot many problems in handling the Electronic and Electrical Equipment (EEE) Waste globally. And day by day there are lot many challenges coming with the updated technologies for handling the whole system of waste in electronic items.

1.5 Key Challenges of E- Waste Management

Informal Recycling: Over 90-95% of e-waste is handled by the informal sector, which uses hazardous methods like acid leaching and open burning, posing severe health risks to workers and contaminating the environment.

Lack of Awareness: Consumers often lack incentives and awareness about responsible e-waste disposal, leading to improper disposal and environmental harm.

Insufficient Infrastructure: Sparse collection infrastructure and lack of authorized recycling facilities hinder effective e-waste management. (SHARMA, 2025) (PwonlyIAS, 2025)

1.6 Government Initiatives

E-Waste (Management) Rules, 2022: Introduced Extended Producer Responsibility (EPR) and a floor price for EPR certificates to encourage formal recycling and discourage informal practices.
EPR Mechanism: Holds producers accountable for the entire lifecycle of their products, promoting sustainable product design and waste reduction.
Digital Tracking: Digitizing the EPR process can enhance transparency and efficiency in e-waste management. (Singh, 2025) (PwonlyIAS, 2025) (SHARMA, 2025)

1.7 Policies and Guidelines of E-Waste In India

India has implemented several policies and guidelines to manage electronic waste (e-waste) effectively. Key regulations include.

E-Waste Management Rules, 2016: Introduced by the Ministry of Environment, Forest and Climate Change, these rules apply to businesses generating e-waste, requiring safe disposal and recycling practices.

Extended Producer Responsibility (EPR) Plan: Companies are responsible for recycling a minimum percentage of their electronic products, with targets ranging from 30% in 2019-2020 to 70% in 2023 and onwards.

Restrictions on Hazardous Chemicals: Limits on the use of hazardous substances like lead, mercury, and cadmium in electronic products, with maximum allowed concentrations specified.

Authorization and Filing Requirements: Companies must obtain authorization from the State Pollution Control Board (SPCB) and maintain records of e-waste handled or generated, filing annual returns.

Key Guidelines:

Collection and Storage: Companies must collect and store e-waste safely, with a maximum storage period of 180 days, extendable up to 365 days.

Immobilization of Mercury: Products containing mercury must be immobilized before forwarding to dismantlers or recyclers.

Labelling and Symbol: Products should bear a symbol indicating they should not be discarded with regular waste.

Regulatory Bodies:

Ministry of Environment, Forest and Climate Change: Nodal agency for policy, planning, and coordination of environmental programs, including e-waste management. (Ministry of Environment, n.d.)

Central Pollution Control Board (CPCB): Provides technical guidelines and oversees implementation of e-waste rules. (Board, 2024)

2. Literature Review

The Literature Review includes some of the relevant research papers and reports which are related to E-Waste in direct or indirect ways. By studying these reports, the scenario of E-Waste and its management systems can be overviewed.
India's rapid technological growth has led to a significant increase in electronic waste (e-waste), posing environmental and health risks. Effective e-waste management is crucial to mitigate these impacts.

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Key Findings

Informal sector dominance: Over 90% of e-waste is handled by the informal sector, using hazardous methods.
Lack of infrastructure: Insufficient authorized recycling facilities and sparse collection infrastructure hinder effective e-waste management.
Regulatory challenges: Existing laws and regulations face implementation gaps and enforcement issues.

Opportunities

Extended Producer Responsibility (EPR): Holding producers accountable for product lifecycles can promote sustainable design and waste reduction.
Block chain technology: Enhancing transparency and efficiency in e-waste management.
Public awareness: Educating consumers about responsible e-waste disposal and recycling practices.

2.1 E-Waste Management – A Case Study of Bangalore India

E-Waste management and recycling were introduced in Bangalore due to the city's rapidly rising waste stream, wasted precious resources, hazardous compounds, and low recycling rate. (12,000 tons of E-Waste per year). Personal computers were designated as tracers, and a model was created accordingly. The process encompassed the tracer's whole life cycle, from creation to consumption, including reuse and refurbishment, until it reached the professional recycling business.
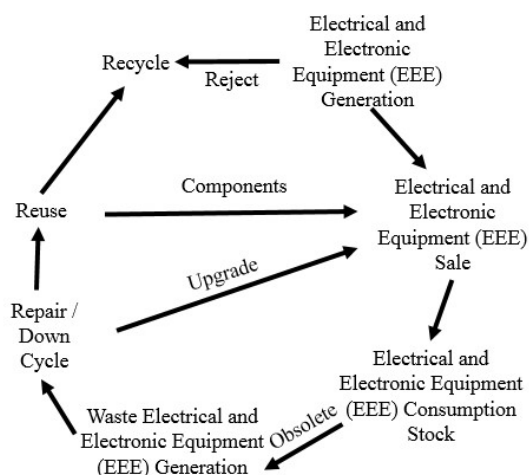
Material Flow of the Pre-Recycling Process of the tracer
Figure 1Pre Recycling Process of the tracer

Based on the result, the two model shows a chain of process.
The system is separated into two sections: Pre-and post-recycling processes. "Recycling" symbolizes a "point of no return".
For Post Recycling process, Mechanical activities include environmentally friendly hand dismantling, segregation, pulverising, and density separation, while metals, glass, and plastics are recovered individually.

Conclusion:
Informal recyclers have extraordinary talents, including the capacity to identify various sorts of raw materials. Informal units frequently operate without a licence in residential areas, endangering the local environment and residents. Informal recyclers should have a training and awareness program on safe E-Waste recycling practices in the current government-approved E-Waste recycling facilities. It is necessary to create cost-effective technologies for extracting valuable metals and disposing of toxic metals. Pre-recycling processes include mechanisms such as: Create more value. To prevent an elevated flow rate throughout the entire system. The impetus is the growing demand for low-cost personal computers among India's rapidly growing computer user population. The market demand generates jobs and business in the second-hand sector while also reducing the overwhelming load of E-Waste. (Sudhir, 2009)

3. Problem Statement

Based on the literature studied and other research articles, there are some problems which are been observed through the study area. As a major area of this research, the case of Vadodara city is been taken. There may be other problems too, but at a glance, looking to the present scenario and studying different articles related to the management of electronic waste, the major problems in the system of managing the electronic waste are mentioned below and these are the emerging issues which needs to be looked upon in the sector of E-Waste in the city of Vadodara.

- Lack of awareness in people about disposal of the E-Waste.
- Role of informal sectors in managing the E-Waste.
- Poor Management Practices for E-Waste Management.
- Human Health and Environmental hazards.
- Implementation of Regulations and Policies.
- Recycling

In today's developing cities, though the people are advanced with the technology but, yes when it comes to the awareness for the knowledge of disposal of electronic waste, particularly, people are not aware for the proper disposal of the electronic waste. The people are not aware, which leads to the improper disposal of electronic waste. Therefor awareness is the major problem for managing the electronic waste.

The role of informal sector is an important part in dealing with electronic waste. The informal sector collects the electronic waste from door to door, and then they adopts improper ways of segregating the electronic waste and then finally adopts improper ways of disposal of electronic waste. Therefore looking on the informal sector is again one of the major challenge, dealing with the electronic waste.

These informal sector because of less knowledge and awareness for treating the electronic waste adopts improper practices methods for electronic waste. These poor management system is also one of the major issues. At the same time it is harmful for the environment as well as for the human risks. These improper practices adopted by the informal sector leads to the hazardous things for the environment as well as the environment.

3.1 Objectives

As such the problems are mentioned above, based on that, the following are the objectives for the research through which it would cater the real challenging issues and at the same time it

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would be helpful to respond to the problems for E-Waste Management.

The following are the objectives for the research areas, which is focused and taken in consideration for a case of Vadodara city.

- To examine the structure and practice of E-Waste Management with respect to system and challenges.

- To analyze the E-Waste Management with specific emphasize on role of informal sector and its socio-economic impact.

- To examine the Policies & related / relevant rules for inclusion of informal sector.

The awareness in the people for the disposal of electronic waste is a burning challenge for the proper management of electronic waste. For that finding whether the people / end consumers are aware or not is the first part. Because they are the main sources from where the electronic waste is majorly generated.

The study of existing scenario is also a major part of the research. It is very important to know what is happening in the market and how the electronic waste is being managed and how it is handled till its end of its life. To study the rules and regulations dealing in the sector of electronic waste, is one of the important part to look at it and know how these rules are implemented in the sector of electronic waste.

These all objectives of the research study will help to study the existing scenario and would be helpful in finding the challenges involved in the whole system. By achieving all this objectives, this will help to analyze the whole situation, and can be helpful to suggest better management plan for proper disposal and management of electronic waste.

3.2 Research Design

Research on the informal sector in electronic waste (e-waste) management involves studying the role, practices, and impact of informal sector workers in collecting, dismantling, and recycling e-waste. Here's a breakdown of the research:

1. Understanding the informal sector's role: Examining the current practices, challenges, and opportunities for improvement in the informal sector's e-waste management.

2. Assessing environmental and health impacts: Investigating the environmental and health risks associated with informal sector e-waste management practices.

3. Identifying strategies for improvement: Developing recommendations for formalizing and integrating the informal sector into the formal e-waste management system.

3.3 Methodology

1. Surveys and interviews: Conducting surveys and interviews with informal sector workers, recyclers, and other stakeholders to gather data on their practices and challenges.

2. Case studies: Conducting in-depth case studies of specific informal sector e-waste management systems or locations.

3. Observational studies: Observing informal sector e-waste management practices to gather data on their methods and impacts.

4. Data analysis: Analysing existing data on e-waste generation, collection, and recycling rates, as well as economic and environmental impacts.
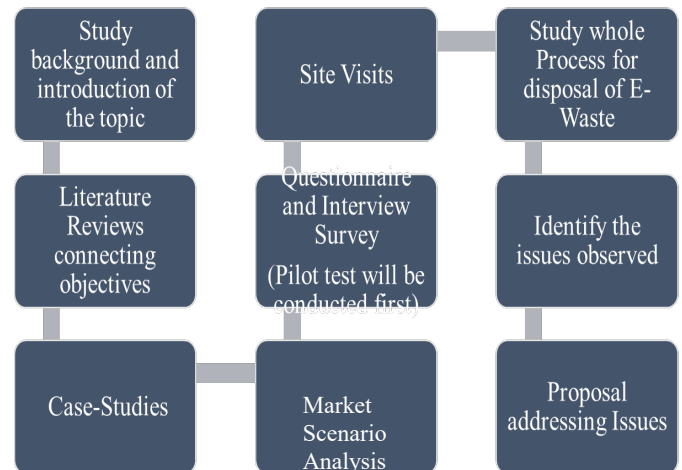

Figure 2 Methodology for Research

3.4 Case Study Approach

Gujarat is one of the leading electronic waste (e-waste) producing states in India. Here's an overview of the electronic waste scenario in Gujarat.

Ahmedabad: With approximately 3,286.5 tonnes of e-waste, Ahmedabad is one of the major e-waste generating cities in Gujarat.

Surat: Generating around 1,836.5 tonnes of e-waste, Surat is another significant contributor to Gujarat's e-waste.

Vadodara: As a major city in Gujarat, Vadodara likely generates a substantial amount of e-waste, although the exact quantity isn't specified.

Other cities in Gujarat that might be generating significant amounts of e-waste include:
Gandhinagar: As the capital city of Gujarat, Gandhinagar could be a significant contributor to the state's e-waste.

Rajkot: Although not mentioned in the search results, Rajkot is a major city in Gujarat and might generate a substantial amount of e-waste.

It's worth noting that Gujarat has 40 authorized e-waste recyclers and dismantlers, with 93 e-waste producers in the state. Ahmedabad has several e-waste management companies, including NEPRA Resource Management, Let's Recycle, and R Planet Integrated Solution. (India, 2022)

3.5 Selection of Study Area

Vadodara's electronic waste management scenario is a growing concern due to the city's increasing technological advancements and electronic device usage. Here's a detailed overview:

Current Challenges:

Informal Sector Dominance: Almost 87% of Vadodara's e-waste is handled by the informal sector, which recycles waste without considering environmental and health impacts.
Lack of Scientific Disposal: E-waste is often disposed of in landfills, contaminating soil and water sources, and posing serious health risks to humans and the environment.

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Toxic Substances: Electronic devices contain hazardous materials like lead, mercury, and cadmium, which require proper handling and disposal. (Ltd, 2012)

E-Waste Management Initiatives:

Authorized Recycling Facilities: Companies like BRP Infotech and Swach Enviro E-waste India Pvt. Ltd. are working towards responsible e-waste disposal and recycling in Vadodara.
Collection and Recycling: Swach Enviro E-waste India Pvt. Ltd. has set up collection centers and recycling facilities to manage e-waste scientifically.
Awareness and Education: Efforts are being made to educate consumers about responsible e-waste disposal and the importance of recycling. (Ltd, 2012)

Regulatory Framework:

E-Waste Management Rules: The Indian government has implemented rules to ensure proper e-waste management, and companies like Palred Electronics Private Limited are committed to following these regulations.
Vadodara Municipal Corporation: The Corporation provides guidelines and services for e-waste management, including a toll-free number for citizens to report e-waste-related issues. (Corporation, 2014)

Major Sources of E-Waste are as under.

Formal Sector	Informal Sector
Importers	Dissemblers
Producers	Smelters
Retailers	Recyclers
Consumers	Scrap Dealers
Traders	

Table 1 shows the major sources of E-Waste

4. Data Analysis

4.1 Primary Data Collection (Quantitate and Qualitative)

As per the data collected from the site visit while interacting with the scrap dealers and visiting Sukravari Bazaar of Vadodara, one can analyse that Informal Sector plays very important role in terms of managing the E-Waste.
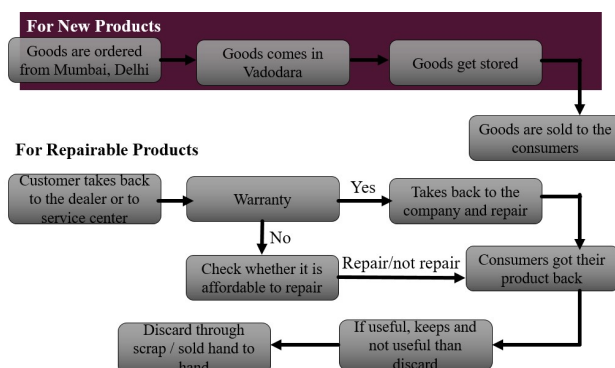

Figure 3 shows the life cycle of Electronic Goods

They visit different places and collect Electronic waste from all over the major areas of Vadodara and also from surrounding villages around Vadodara like Savli, Padra, Sinor, Dabhoi. Finally all this collected waste sometimes the informal sector dismantles by themselves and then if some parts are useful or some repairable items are given for sale in the second hand market. For example Sukravari Bazaar.
The scenario of dismantling the items is also shown in the following images. The images were taken while visiting the Sukravari Bazaar at Vadodara and then visiting one of the scrap dealer's house where he performs all the operations.
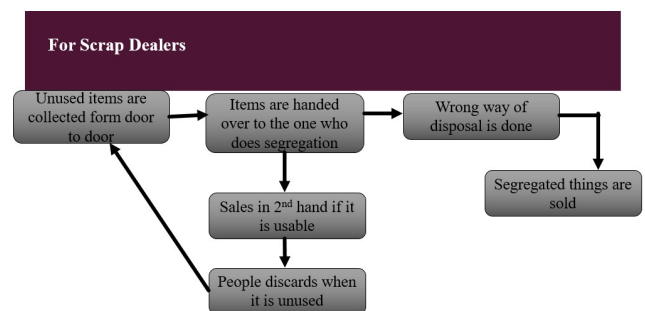

Figure 4 shows the operation of Electronic Goods

Figure 5 Informal sector dismantling the e-waste

The scrap dealers visit almost major areas of Vadodara and surrounding the Vadodara city. There are some peri urban areas surrounding villages are also covered for collection for the informal sector. The people working in this sector are all inter connected with each other and their team manages to cover major areas for collection.

Figure 6 Vadodara Map showing surrounding villages

4.2 Questionnaire Survey

1. Citizens / Consumers

2. Small and medium Scale Enterprises (SMEs) - Universities, IT training centers, Small training centers dealing with bulk in computers.

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For Pilot Survey, 20 Citizens / Consumers were approached for the filling of the form with Questionnaire.

Around 6 Small and Medium Scale Enterprises were approached for the filling of the form with Questionnaire.

And for interview Survey, ECS Environment Pvt. Ltd company at Vadodara is approached.

For informal Sectors around five to six scrap dealers were interviewed.
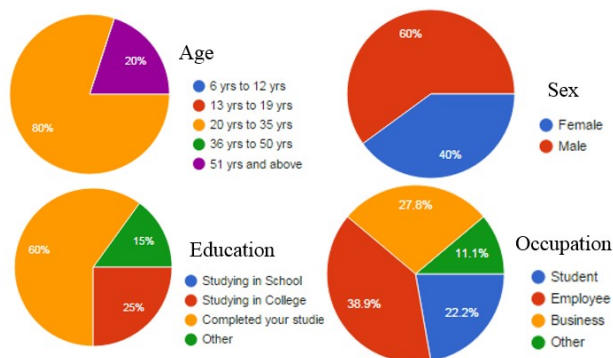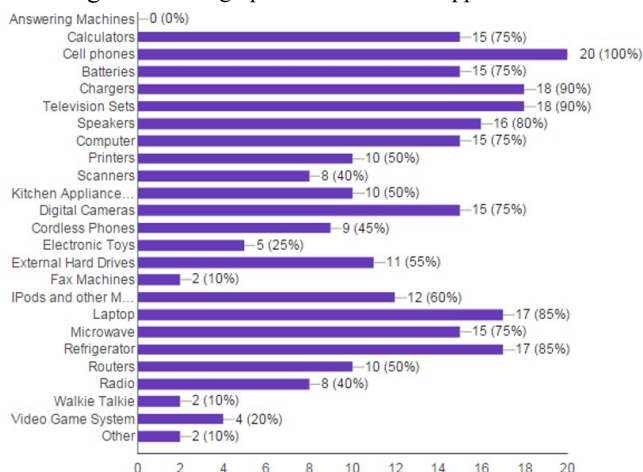

Figure 7 Demographics of consumers approached.

Figure 8 usage of Electronic and Electrical Equipment.

Mostly people try to repair first, but when it is not affordable to repair, people try to discard through second hand sales and gives to scrap dealers.
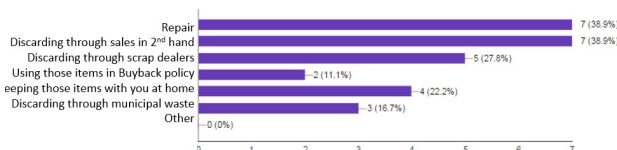

Figure 9 disposal ways adopted by consumers for the E-Waste.
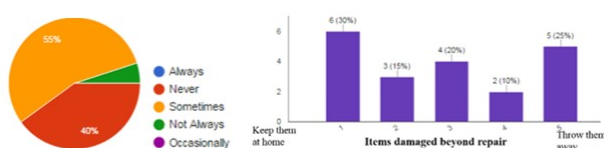

Figure 10 shows the option opted by consumers

People use policy for buy back as per the chart below. And also if any item is damaged beyond repair, than the graph below shows that how many people keeps at home and throw them away.
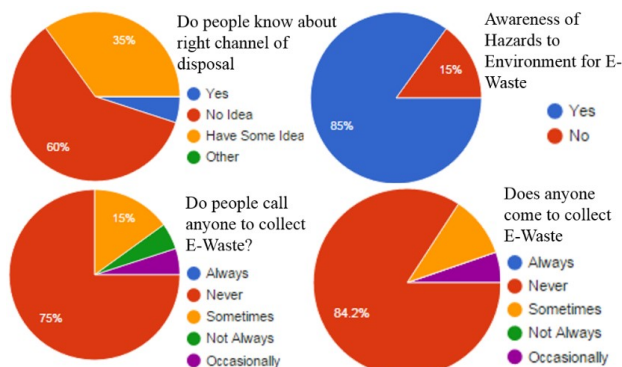

Figure 11 shows the awareness of E-Waste in consumers

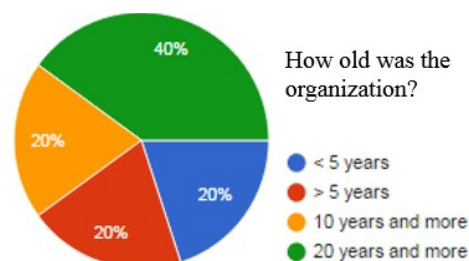**For Small and Medium Scale Entrepreneurs**
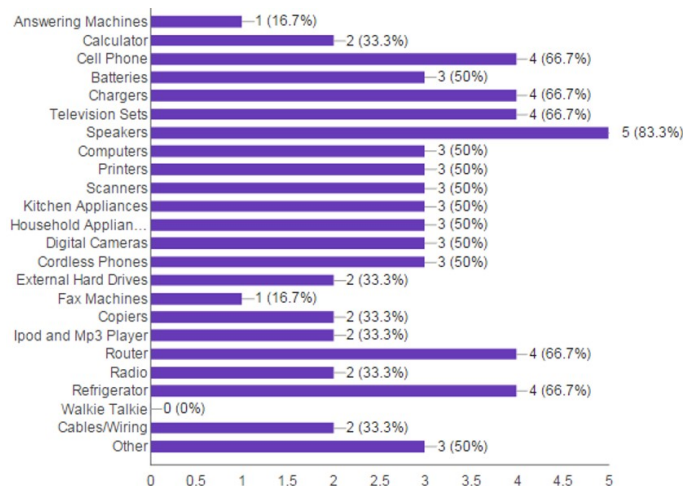

Figure 12 shows how old is organization

Figure 13 shows the usage and dealing with the types of EEE.

Majority of them are discarding electronic waste through scrap dealers

4.3 Focus Group / in Depth interviewing

1. Informal sectors (Scrap dealers of E-Waste)

2. Companies dealing with E-Waste (ECS Environment Pvt. Ltd, E-coli Waste Management)

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Interview with ECS Environment Pvt. Ltd.

ECS Environment Pvt. Ltd. is an ISO 9001, ISO 14001, and ISO 18001 certified company that facilitates the integration of quality, environmental and occupational health and safety management systems by organization. Four years back they approach all corporations. 2 years back Vadodara Municipal Corporation gave them support and started initiatives for collection of E-Waste in Vadodara. Tie ups with SBI bank, UTI bank for always collection of E-Waste. Spreading awareness in school. They specially segregate all printed circuit boards, whose disposing is very critical, they send all to Japan with special permission from MOEF. [There are only 3 companies for this in India.]

Problems faced by ECS:
- People are not aware of disposing of E-Waste

- Can't give the money which scrap dealer gives to the people.

- Can't come to collect small quantity of E-Waste.

4.4 Introducing GPS for informal sector

As part of the initial survey, kabadiwalas' waste collection routes were tracked in real time. The kabadiwalas do not have defined work schedules because their employment is informal. Because their daily pay is directly proportional to the amount of rubbish collected, their primary goal is to work until they have gathered enough waste to cover their expenses for the day. However, their employment patterns are influenced by a variety of societal factors, including age, health status, and the festive seasons in India. Their flexible work schedule has an impact on the distance they travel daily to collect rubbish as well as the number of waste collection actions they perform each week. Each kabadiwala is assigned to a certain area of Vadodara for rubbish collection, resulting in the average travelling distance can be known.
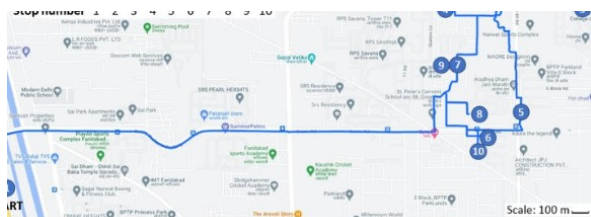

Figure 14 shows one example of gps tracking

5. Conclusion

Bridging the gap between the formal and informal sectors in collecting electronic waste (e-waste) in Vadodara City is crucial for effective e-waste management. By integrating the informal sector into the formal system, the city can manage the E-Waste. Effective e-waste management in Vadodara requires a multi-faceted approach that involves government, industry, and civil society. By implementing sustainable practices, promoting awareness, and encouraging responsible e-waste disposal, Vadodara can mitigate the environmental and health impacts of e-waste.

Key Benefits

1. Improve collection efficiency: Formalizing the informal sector can increase e-waste collection rates and reduce waste disposal in landfills.
2. Enhance environmental and health safety: Regulated e-waste collection and disposal practices can minimize environmental pollution and health risks.
3. Promote sustainable e-waste management: Collaboration between formal and informal sectors can foster a circular economy and encourage responsible e-waste management practices.

Strategies for Bridging the Gap

1. Training and capacity building: Provide training and capacity-building programs for informal sector workers to adopt safe and environmentally friendly e-waste collection and handling practices.
2. Incentivization: Offer incentives to informal sector workers to participate in formal e-waste collection systems.
3. Partnerships and collaborations: Foster partnerships between formal and informal sector stakeholders to develop effective e-waste management systems.

Benefits

Improved Transparency: GPS tracking can provide real-time data on e-waste collection routes, locations, and quantities.
Enhanced Accountability: Informal sector workers can be held accountable for their collection practices, promoting responsible e-waste management.
Better Data Collection: GPS tracking can help collect accurate data on e-waste generation and collection patterns.

Challenges

Infrastructure and Cost: Implementing GPS tracking requires investment in infrastructure, including devices and data analytics capabilities.
Worker Buy-in: Informal sector workers may resist adopting new technologies, requiring education and training.
Data Security: Ensuring the security and integrity of GPS tracking data is crucial to maintaining transparency and accountability.

Potential Impact

Formalization of Informal Sector: GPS tracking can help integrate the informal sector into formal e-waste management systems. Improved E-Waste Management: GPS tracking can promote responsible e-waste collection and disposal practices, reducing environmental and health risks.

By leveraging GPS tracking technology, Vadodara can take steps towards formalizing the informal sector and improving e-waste management practices.

Way Forward

By bridging the gap between the formal and informal sectors, Vadodara City can develop a comprehensive and sustainable e-waste management system that benefits both the environment and the local economy.

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