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An Overview of Solid Waste Management Practices in Pune, Maharashtra, India

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ABSTRACT

The growing population and rapid urbanization are significant challenges for Indian cities. Pune City generates nearly 2,258 tonnes of waste per day. Pune's informal waste sector has demonstrated remarkable efficiency, cost-effectiveness, and self-sustainability. Moreover, it contributes to favorable economic and social outcomes for the city. With the support of the self-help group SWaCH Seva Sahakari Sanstha Maryadit, Pune, the municipal solid waste management model has successfully achieved a remarkable 95 percent segregation rate. Implementing the Pune municipal solid waste management model showcases the active and efficient engagement of informal waste workers in the collection and resource utilization process. This underscores the possibility of favorable economic, social, and environmental results stemming from collaborations between municipalities and waste pickers. This paper looks at the role of SWaCH in line with Pune Municipal Corporation towards the present waste management system. Primarily reliant on labor, this model accomplishes recycling tasks at a notably lower cost compared to conventional mechanized and centralized waste management approaches. It can also accomplish high recycling levels and relatively considerable plastic waste segregation. Promoting the retrieval of valuable materials, especially plastics, for local and global recycling enterprises actively contributes to the advancement of a circular urban waste management approach. The objective of this research is to explore and provide a realistic understanding of Pune's current status of waste generation, collection, transportation, and disposal. Apart from the SwaCH-PMC model, the paper also focuses on plastic waste recycling, the Red Dot Campaign towards sanitary waste, and household e-waste management in Pune.

INTRODUCTION

Global and Indian concern lies in the current challenges of municipal solid waste management in urban areas, including megacities and smaller villages. Rapid urbanization, economic development, and population growth increase waste generation rates, posing diverse risks to the environment and public health. Municipal authorities struggle to cope with the accelerating pace of waste generation, making solid waste management a vital municipal responsibility. India has a lack of awareness about solid waste management, but it has evolved over the years. The majority of solid waste is not properly treated, with waste segregation being a major obstacle. Factors such as improper collection, transportation unavailability, lack of treatment technologies, and financial shortages contribute to poor waste management practices. Different waste streams have varying hazards, and ranking wastes based on their level of hazards offers economic advantages. MSW is a composite made up of a variety of waste materials produced by residents of the area. MSW is divided into several fractions, including recyclables and non-recyclable materials that can be composted. The amount and makeup of garbage are influenced by a number of variables, including average income, living standards, population size, social behavior, climate, industrial production, etc. (Bamne & Mhatre 2019).

In the Pune Municipal Corporation (PMC), there are 42 wards and five zones. Also one of the largest Municipal Corporations in Maharashtra. On July 1st, 2021, it underwent a process of delimitation, adding 23 villages to its jurisdiction (Alappuzha 2021). Previously, the city was administered through the P.M.C. through four administrative Zones, each of which was further subdivided into three or four Wards and subsequently into three or four Prabhags. At the most basic level, Kothis are divided into 152 Kothis, 76 Prabhags, 14 Wards, and 4 Zones (Sohkhlet & Nagargoje 2020). Pune Municipal Corporation has used segregation since at least 2008 (Alappuzha 2021). A population of 3.5 million people lives in an area of 244 square kilometers (Kumar & Agrawal, 2020).

SCOPE AND METHODOLOGY OF STUDY

The research objective is to understand the current management of solid waste in Pune, from collection to disposal. This involves analyzing the existing problems, challenges, and potential prospects within the solid waste management systems. The study's methodology is based on qualitative data. To assess the various issues, underlying causes, and negative outcomes related to solid waste management in Pune, secondary data is sourced from diverse outlets such as Research Papers, Annual Reports, Websites, Journals, Government Websites, and publications.

SWaCH: A TRANSFORMATION TOWARDS THE PUNE MUNICIPAL SOLID WASTE MANAGEMENT SYSTEM

Starting from the early 1990s, when Pune, much like numerous cities in India, operated a waste collection system based on communal bins where residents deposited their solid waste every day, and the informal waste pickers to recover recyclables, the city has grappled with escalating amounts of municipal solid waste. The city's underprivileged waste pickers banded together in 1993 to organize their union, known as Kagad Kach Patra Kashtakari Panchayat (KKPKP), to voice their right to dignity and a secure livelihood. They were poor, illiterate, silent, disregarded, and even condemned by some (Le Doze et al. 2018).

The Kagad Kach Patra Kashtakari Panchayat (KKPKP) came up with a sustainable strategy for municipal solid waste management and collaborated with municipal commissioners to advance a decentralized approach. This collaboration was established in conjunction with other civil society organizations dedicated to addressing environmental concerns at the city level (Rode 2011). To convince the Pune Municipal Corporation (PMC) that waste pickers perform essential urban environmental services, Kagad Kach Patra Kashtakari Panchayat (KKPKP) combined research, policy, and political assistance. To obtain official authorization to provide primary garbage collection services, Kagad Kach Patra Kashtakari Panchayat (KKPKP) successfully collaborated with PMC. Given that the PMC's efforts with KKPKP led to Pune becoming one of the first local administrations in India to provide waste pickers with identification cards and health insurance premiums (Le Doze et al. 2018). In the year 2000, public interest litigation over poor municipal solid waste management in major cities resulted in significant changes in national policy, resulting in the National Municipal Solid Waste Law (Management and Handling) Rules 2000 (Rode 2011). These regulations mandate urban authorities to conduct door-to-door waste collection, promote household waste separation, and redirect waste from landfills to recycling and processing systems. The Kagad Kach Patra Kashtakari Panchayat (KKPKP) implemented a door-step waste collection system for 50,000 properties in the city, backed by the local body through citizen pleas and basic equipment like pushcarts and buckets, to reduce littering and promote waste management. (Le Doze et al. 2018).

In 2007, PMC collaborated with informal waste collectors Kagad Kach Patra Kashtakari Panchayat (KKPKP) to implement the Municipal Solid Waste Rules 2000. Cities were required to submit action plans by December 2007, aiming for 100% door-to-door collection. PMC chose waste picker cooperatives for waste management, with a user fee for door-to-door collection. This prompted the establishment of the PMC-SWaCH cooperative model, resulting in a profound impact on the city's system for managing municipal solid waste (Rode 2011). In 2008, the Pune Municipal Corporation (PMC) granted authorization to SWaCH, India's pioneer cooperative owned by independent waste pickers, to offer doorstep waste collection and waste management services for a duration of five years. The waste pickers are compensated with a service fee and are responsible to both the residents and the PMC.

Waste pickers sort and sell the recyclable materials they collect, and they keep all of the revenue that they make (Alappuzha 2021).

SWaCH, a group of over 80% women, works with representatives from Kothi Councils and the city-level Representatives Council to facilitate workers' participation in decision-making processes, including waste pickers and waste management. At the Kothi level or within neighborhoods, coordinators collect user fees, handle grievances, and offer additional benefits such as composting and the collection of electronic waste. They bridge the gap by recovering reusable waste and supplying essential resources for the official recycling process (Le Doze et al. 2018). In 2013, SWaCH serviced over 390,000 properties in Pune with 2,200 members. The model remained in place without administrative support for two years, with a team of 14 coordinators and staff. PMC renewed the contract in 2016 for five years, and by August 2018, SWaCH had serviced 640,000 properties with 3,076 waste pickers. Therefore, Fig. 1 provides an illustrated timeline of the Pune waste management journey from 1993 to 2018. The revolutionary work of Kagad Kach Patra Kashtakari Panchayat (KKPKP) and the sustainability of the SWaCH model led to the inclusion of a trade union representing informal waste pickers in the Municipal Solid Waste Rules 2016. The incorporation of waste pickers into the municipal solid waste management system, requiring urban areas to provide identity cards

and doorstep collection services, is currently legal (Rode 2011).

SOLID WASTE MANAGEMENT: AN OVERVIEW OF PUNE CITY

According to reports, the city creates almost 2,258 tonnes of garbage every day. Pune believes that biogas cleans the city and is experimenting with ensuring that no trash goes to landfills. With a population of 3.5 million people and an area of 244 square kilometers (Alappuzha 2021). They generate approximately 400 g of solid trash per capita. The city expects trash generation to be 3,255 tons by 2025 and 3600 tons by 2031 and is looking at more intensive technologies such as a biogas plan. An overview of the solid waste management system is shown in the Fig. 2 for Pune. Thermal gasification is used in decentralized vermicomposting, RDFS, recycling, and waste-to-energy systems. Households create over 70% of municipal solid garbage, while hotels, restaurants, and other commercial entities account for the remaining 30% (Kumar & Agrawal 2020). As per the current studies, Pune City processes about 2,258 tons of waste each day, the majority of which is organic and comes from 70% of the household population. The first municipal-based biogas plant was created in the colony model with a location of 4000 inhabitants around 375 units of energy had enough power to run 250 streetlights and generate 150 tons of compost in 2014; approximately 20 such biogas facilities were operational, with potential increase to 27 or more. Pune Municipal Corporation, PMC, owns models based on public-private partnerships. The operator of the biogas facilities is paid Rs.600,000 per month for maintenance, with an annual increase of 10% - 15%. The facility opened in 2010 at a cost of Rs.60 lakhs (Kumar & Agrawal 2020).

Presently, with the higher price of Rs. 30 lakhs, PMC has paid Rs.1300 to Rs.1400 per tonne for one ferrying of waste to the facility. The collaboration has already begun receiving

1993: Waste pickers in Pune form the Kagad Kach Patra Kashtakari Panchayat (KKPKP) union.
1995: The report of the Planning Commission's High-Power Committee on Solid Waste Management in India recommends incorporating waste pickers, forming cooperatives for door-to-door waste collection, segregation, recovery centres, recycling incentives, and composting for improved waste management.
2000: The Municipal Solid Waste (Management and Handling) Rules mandate doorstep collection, promote trash segregation at the source, dry waste recycling, and waste diversion away from landfills.
2002: Maharashtra government resolution allocates labor for door-to-door garbage collection through user-fee cooperative rubbish pickers.
2006: The Maharashtra Non-Biodegradable Solid Waste (Proper and Scientific Collection, Sorting, and Disposal in Municipal Corporation Areas) Rules establish safe sorting spaces (material recovery facilities) for waste pickers, allowing recyclable items to be diverted through the informal sector.
2007: Maharashtra's Urban Development Department mandates December 2007 deadline for city action plans to implement Municipal Solid Waste Rules 2000, promoting 100% door-to-door collection.
2008: Pune Municipal Corporation authorizes SWaCH cooperative to offer door-to-door waste collection and management services for five years.
2012: Central Ministry mandates waste pickers recognition, identity cards, and personal protective equipment for solid waste management, integrating them into municipal solid waste management systems.
2013: SWaCH and PMC sign a memorandum, ending with over 390,000 properties serviced.
2014 - 2015: Without PMC administrative support, the SWaCH model persists.
2015: The government's drafting committee for the revised Solid Waste Management Rules (due for release in 2016) is comprised of informal waste pickers, who are represented by KKPKP.
2016: Solid Waste Management Rules acknowledge informal waste pickers, collectors, and recyclers as crucial elements of solid waste management, requiring registration, identification, material recovery facilities, and training for waste pickers.
2016: The PMC renews its five-year agreement with SWaCH.
2016: In the government's drafting committee for the 2016 Solid Waste Management Rules, KKPKP represents informal waste collectors.
2018: SWaCH expands to cover 640,000 properties, employing over 3,000 waste-pickers.

Fig. 1: Institutionalizing door-to-door waste collection service in Pune by involving waste pickers: A timeline (Le Doze et al. 2018).

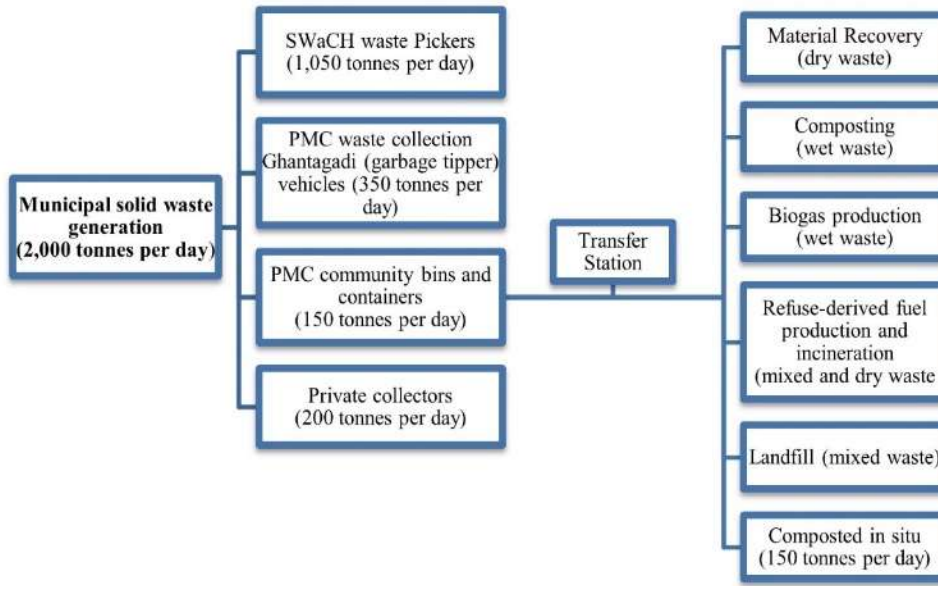

Fig. 2: Municipal solid waste management system in Pune City (Le Doze et al. 2018).

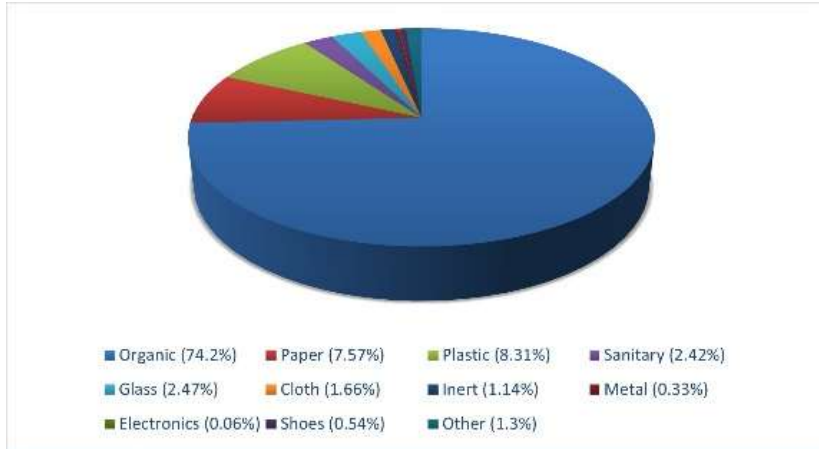

Fig. 3: Municipal Solid Waste Composition in Pune (Alappuzha 2021).

well-managed separated garbage from hotels, which families can directly transfer to the bio-methanation plant (Kumar & Agrawal 2020).

Unsegregated waste generators are likewise subject to the PMC penalty system. A property tax incentive is available to anyone who installs eco-friendly building methods such as solar heaters, rainwater collection, and compost pits. PMC ensures that there is no foul play by doing frequent inspections and rescinding the reimbursement if it is discovered to be nonfunctional. With the support of the self-help group SWaCH Seva Sahakari Sanstha Maryadit, Pune, it has achieved 95 percent segregation (Alappuzha 2021).

Waste Classification and Composition

The Public Health and Sanitation Bye-Laws of 2014 include a comprehensive classification of waste comprising 25 categories. Municipal Solid trash encompasses commercial, residential, and other trash created in a municipal or notified area, except industrial hazardous waste and treated bio-medical waste. The classification is based on the source of trash generation, which can be residential, commercial, educational, public and private gardens, heritage structures, or religious locations. (P.M.C 2014). Fig. 3 illustrates the typical waste composition that is generated.

Biodegradable waste, including tea leaves, eggshells, fruit and vegetable peels, meat and bone fragments, and

animal waste, is considered wet waste. Recyclable waste, including paper, metal, plastic, rubber, and glass, is also known as dry waste. Construction and demolition waste, or "C&D waste," refers to waste generated during the construction, renovation, maintenance, and demolition of homes and businesses (Alappuzha 2021). E-waste includes information technology, telecommunications equipment, consumer electronics, and related trash, while hazardous components in household cleaners, automobiles, personal care products, and related items are classified as commercial/household hazardous, biomedical, and sanitary waste (P.M.C 2014).

Waste Collection

P.M.C. introduced a standard user charge for door-to-door collections in 2017, tracking management, equipment acquisition, and maintenance expenses (Alappuzha 2021). A hierarchy of waste collection processes is represented below in Fig. 4. Municipal solid waste is collected through primary and secondary methods. Door-to-door services, including Solid Waste Collection and Handling (SWaCH), account for 43% of the total collection. Tipper trucks, also known as "ghantagadi," collect recyclable and nonbiodegradable waste from building gates via Prabhags, accounting for 12% of the primary collection. Both methods involve unorganized workers and community-based cooperatives (Sohkhlet & Nagargoje 2020).

Pushcart services are available in urban areas that are inaccessible to trucks. After that, the waste gets transported to a station located within each ward. Dumper Placer trucks that additionally transport waste to the transfer station make up 40% of the primary collections. P.M.C. also collects waste that has been abandoned along roads and streets to be transported to the stations, accounting for 5% of all the primary collections (P.M.C 2017).

Waste is subsequently transported from transfer stations to dry or wet waste processing plants by Bulk Refuse Carriers (BRC) compactors. Currently, C&D garbage is being disposed of directly in low-lying places along waterways (Alappuzha 2021). Out of the 524,778 houses, P.M.C. supplied door-to-door services to 52.70 percent of them in 2010. This suggests that the other 47.3 percent of households dispose of their waste in community bins. 2017 saw a 55% increase in this. SWaCH covered 80.37 percent of premises in Pune's 41 Prabhags during 2016 and 2017, leaving 19.63 percent of houses unserviced and about 100 TPD uncollected (Le Doze et al. 2018).

Waste Disposal

There are currently 50 processing facilities comprising 7 transfer stations, 25 decentralized biogas plants, 14 decentralized biodigesters, and 4 mechanical composting facilities, which together process 30% of garbage. SWaCH diverts 10% of collected garbage. 60% of the remaining waste is sent to the Urali Devachi dump, located 25 kilometers from the city (Sohkhlet & Nagargoje 2020). The landfill site is 43 hectares in size, 15 ha of which are fully utilized and have been permanently sealed off. Both biodegradable and non-biodegradable materials are included in the waste that is disposed of in landfills. The annual cost of collecting, moving, and disposing of waste is projected to be 83.60 crore rupees (11.8 million USD). A landfill receives unprocessed waste (36% of the total waste) (Hemalata 2012). At present, the plants are running at 51% of their installed capacity.

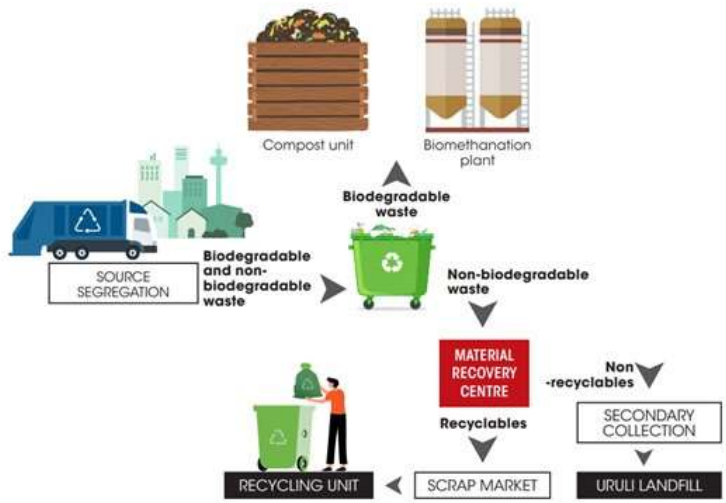

Fig. 4: Process of waste collection in Pune (Alappuzha 2021).

The Clean City Movement and Smart Garbage Management System are initiatives by P.M.C., utilizing GPS and tracking technologies to monitor vehicles and inform citizens. The Katraj Model, a Zero Garbage Ward, aims to reduce landfill waste and promotes the Swachh Awards. 25 decentralized bio-methanation facilities and other composting techniques are operational, and waste-to-energy models using bio-conversion processes generate biogas, promoting sustainable waste management (Sohkhlet & Nagargoje 2020). Pune recently installed a 300 MTD plant capable of producing 11 MW (Le Doze et al. 2018). The Rochem plant, a decentralized waste treatment facility, employs pyrolysis gasification to reduce transportation requirements and promote community engagement. Since 2010, these scientific landfills have been operational, ensuring a reduction in transportation costs and preventing leachate leakage (Kumar & Agrawal 2020). The SWM model in Pune faces challenges due to its size, funding, upgrading, and expertise requirements. Technological solutions like waste incineration and mechanized processing options are vulnerable, causing gaps between processing capacity and actual waste. The current disposal procedures for C&D waste in low-lying areas along rivers also require specific procedures (P.M.C 2017).

PLASTIC WASTE: AN OVERVIEW

The Maharashtra government banned various plastic items, including bags, disposable items, and plastic decorations, on March 23, 2018. The ban applies to individuals and entities, including makers, sellers, and customers. A milk package buy-back scheme and PET bottle buy-back were introduced. Severe penalties apply to those handling or using restricted substances. Although the ban aims to reduce non-recyclable and low-grade plastic in municipal waste streams, it also presents challenges for recycling plastic trash (Le Doze et al. 2018).

Plastic garbage was classified into 30 distinct categories based on how it is handled for recycling/processing. The breakdown of plastic type, generation, and recovery is illustrated in Table 1. In general, 34% of plastics were rigid, while 64% were flexible (single- and multi-layer). Waste pickers recover 37% of plastics.

For recycling, on average. However, the relative recycling rates of different forms of plastic vary significantly. The most recycled plastics are mono-material hard plastics (PET, HDPE, and PR). Transparent, monolayered flexible polymers are more recyclable than colored counterparts in the flexible plastics industry. The recovery rates of multi-layered polymers are the lowest. Instead of being disposed of with organic garbage, compostable plastics are placed in the flexible plastic stream. (Narayanan & Anantakrishnan 2022).

Plastic Waste: Recycling

Prior to being sent to the end consumers of recovered plastic, who produce new plastic products in India or abroad, small and large plastic recyclers process plastic waste further. They concentrate largely on processing plastic as shown in Fig. 5 (sorting, cleaning, flaking, and pelletizing) (Le Doze et al. 2018). Also, the plastic waste recycling value chain hierarchy Not only is Pune City home to plastic waste processing facilities but Maharashtra state as a whole is also home to numerous such facilities, some of which specialize in certain recycling chain processing operations. There are two types of 'recycling' that materials undergo:

a) Closed-loop recycling: When recycled materials are utilized in applications that are similar to those of the original products, such as the bottle-to-bottle recycling of HDPE plastic granules formed from HDPE bottles into HDPE bottles. The majority of PP and HDPE plastics are recycled in closed-loop systems.

b) Open-loop recycling (downcycling): When products manufactured from recycled materials cannot be recycled themselves and the recycled materials are used for a different use than the original products. The plastic that is recycled the most is PET.

Multi-layered and multi-material plastics are very light in weight and highly voluminous, making them considerably more expensive to handle. They are made of multiple distinct layers and types of plastic, paper, and metal. Because they are largely used for food packaging, these polymers are frequently polluted, which attracts rats and makes them difficult to store.

Even when they are gathered for recovery, recycling them still presents technical difficulties. The combination of plastics and non-plastic materials, such as metal and paper, makes this heterogeneous material difficult to recycle technologically (Narayanan & Anantakrishnan 2022).

A method for collecting multi-layered plastics was established in Pune in 2019 by SWaCH Plus with assistance from ITC Ltd to address this waste management

Table 1: Plastic generation and recovery rates (Narayanan & Anantakrishnan 2022).

Plastic Type	Generation (TPD)	Recovery (%)
Rigid	33.7	69%
Flexible	48.0	22%
Multi-layered	14.7	8%
Compostable	0.0	68%

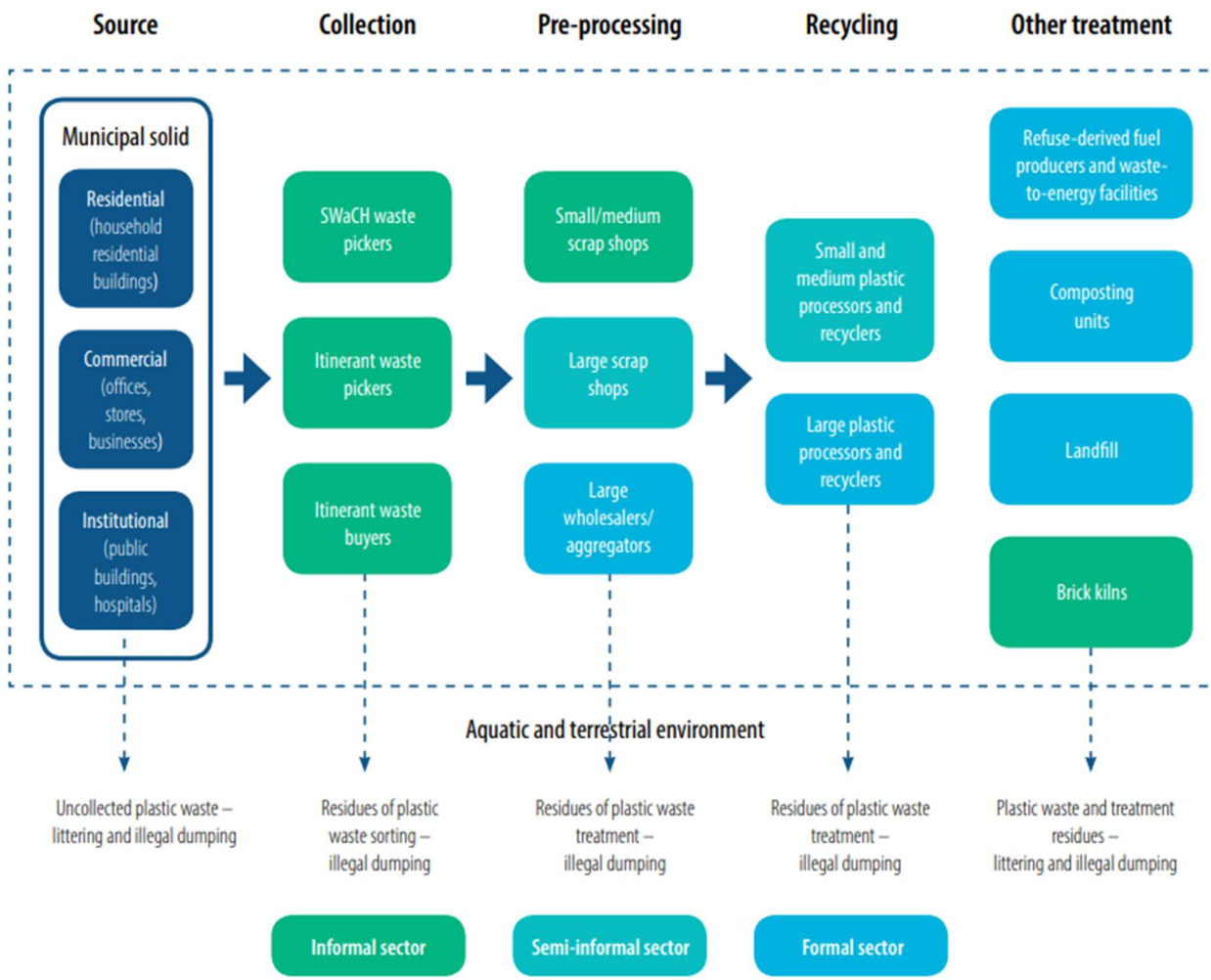

Fig. 5: Plastic waste recycling value chain in Pune (Le Doze et al. 2018).

Fig. 6: SWaCH waste pickers segregating plastics (Narayanan & Anantakrishnan 2022).

and environmental concern. Three tonnes are collected each day at the moment. To prevent overrepresenting the recovery rate for this material using the extrapolation method, data from areas where this system was in operation were separately gathered and excluded in the household waste audit. Since this approach provides city-level data, it may be combined with the 'natural' recovery by waste pickers as shown in Fig. 6 to provide an accurate estimate of the material's diversion to recycling in Pune (Alappuzha 2021).

As of now, mechanical recycling has received 2200 MT or 70% of the total gathered. The materials gathered by SWaCH Plus are a mixture of mono-layered flexible and multi-layered plastics, as well as multi-layered plastics that have been metalized, colored flexible plastics, and some clear, flexible plastics. The quantity of multi-layered plastics is thought to account for 50% of all plastics handled, according to composition data from SWaCH Plus. It follows that of the 3 tonnes per day collected using this approach, around 1.5 tonnes are made of metalized multi-layered plastic, resulting in an effective recycling rate for multi-layered plastics in Pune of 18% (Supe et al. 2021) .

RED DOT CAMPAIGN: AN INITIATIVE TOWARD SANITARY WASTE

As a part of the Information, Education, and Communication (IEC) initiative run by PMC and SWaCH, the campaign was launched in 2016. The motive was to collect sanitary waste separately, with workers collecting waste from door to door. The interactive nature of the campaign led to a better understanding of the issues and approaches of the citizens (Narayanan & Anantakrishnan 2022). According to the Municipal Solid Waste Management Rules, 2016, and in support of this, PMC encouraged citizens to dispose of their sanitary waste separately (Notification No. S.O. 1357 (e) dated April 8, 2016). Only fifty percent of the residents served by the PMC separated sanitary garbage from other rubbish, according to data obtained by corporation officials. Waste is transported to a feeding station (Fig. 7) by workers who collect it door to door. Each feeder site, which offers waste collection services to 100 to 150 houses, is staffed by five to seven people. A PMC collection van then comes and collects the trash. Waste is transported to the transfer station by the PMC vehicle. Following that, sanitary waste is moved in a red container to the processing plant (Alappuzha 2021).

Collection And Transportation of Sanitary Waste

An average of 1.5 TPD is collected and transported for sanitary waste. Currently, SWaCH staff collect residents' sanitary waste either in a separate plastic bag or a paper cover with a red dot (Fig. 8).

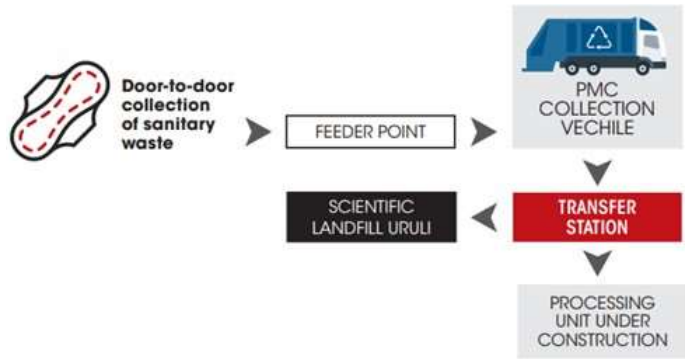

Fig. 7: Process of sanitary waste management in Pune (Alappuzha 2021).

Fig. 8: Sanitary waste collection by waste picker in Pune (Agarwal 2017).

The sanitary waste is then transported to the feeder site using the designated box in the PMC vehicle. Extra bags are utilized and hung separately in the collection vehicle when there is more waste than normal (Agarwal 2017). At the transfer point, sanitary waste is taken out of the PMC vehicle and placed in a red bin. After that, the container is delivered to the research landfill. Every day, all of the sanitary waste is collected. Processing of it is presently underway in Pune's Uruli Scientific landfill (Alappuzha 2021).

Technology

In order to establish a sustainable recycling loop in the sanitary waste industry, an Italian company created a ground-breaking recycling technology that can recycle used absorbent hygiene products, such as baby diapers, feminine hygiene (fem care), and adult incontinence products, to create new products and materials with added value. In Spresiano, northern Italy, the technology is set up and running on an industrial scale (Le Doze et al. 2018). Each year, it can process 10,000 tonnes of spent absorbent hygiene items. Serving a million people would be equivalent to this. The plant is one of a kind and the original in the globe. Using this process, sanitary waste is effectively broken down into plastic, cellulose, and super-absorbent polymers as explained in Fig. 9. These materials can be used to make garden barriers, hard bottle caps for purposes other than food, and viscose clothing.

The sanitary waste processing facility's installation started in 2019, however, because of COVID-19 and a discrepancy in the contractor and PMC's contract, it will take an extra six months to finish. The proposed plant could process ten tonnes of sanitary waste every day. All of the sanitary garbage is picked up each day. It is presently being managed at the scientific landfill near Uruli, Pune (Alappuzha 2021). SWaCH and PMC are working to bring behavioral change to lower-income households through a well-thought-out appeal and plan. However, affluent households have shown more acceptance and are more accepting of the change, demonstrating their involvement in the system. Workers for the PMC were reluctant to touch or collect sanitary trash at the feeder point (where collected garbage accumulated). When the SWaCH team and PMC management took steps to spread knowledge of the proper treatment of sanitary waste, the PMC employees responded and joined the campaign. One of India's major Information, Education, and Communication (IEC) initiatives is the Red Dot Campaign, which aims to inform people about their duties when handling sanitary waste.

E-WASTE MANAGEMENT: AN OVERVIEW

Global concerns about e-waste volumes, limited treatment infrastructure, illegal trade, and consumer awareness have influenced the development of e-waste management legislation. Informal recycling practices, offering functional comfort and cost advantages, have dominated due to negative environmental and health consequences (Arora 2008). Indian cities, including Pune, face challenges in waste management due to informal sectors, non-segregation, inadequate collection/treatment centers, and lack of e-waste inventory. These factors require an organized approach and adaptable systems for handling e-waste and catering to localities. Solutions should be adaptable and convenient, addressing the interconnected scenario. Pune, a proposed smart city, faces challenges in solid waste treatment due to inadequate sites and infrastructure, with untreated e-waste often remaining in whole or trace form, resulting in environmental impact (Link 2016).

Pune, the cultural hub of India, is renowned for its Zero waste concept and Public-Private Partnership (PPP) strategy, involving Municipal Corporations, NGO organizations, and corporations like Cummins India. This model focuses on e-waste management, involving all sources of e-waste generation. Fig. 10 illustrates several waste sources in the

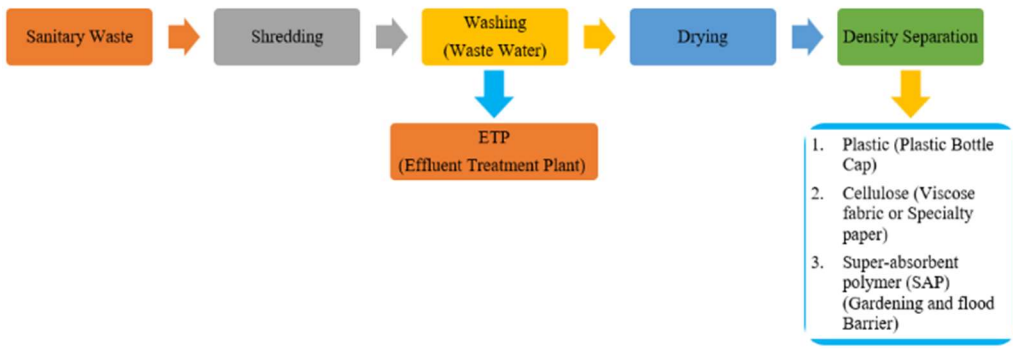

Fig. 9: Processing unit cycle for sanitary waste treatment (Alappuzha 2021).

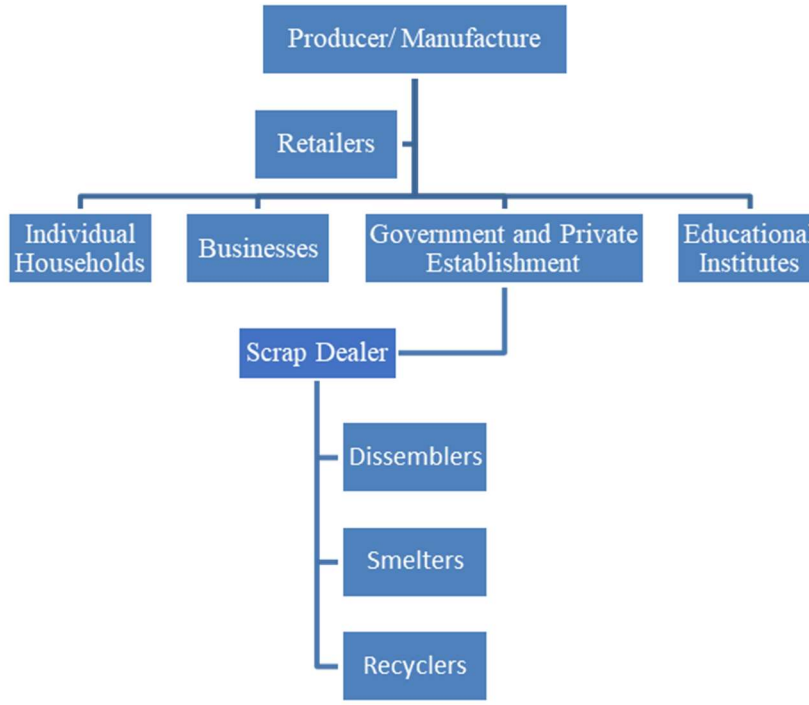

Fig. 10: Stakeholders' hierarchy in E-waste management (Bhat & Patil 2021).

Pune region, illustrating the point of starting to develop an integrated model (Chhura & Kumar 2015).

The government has implemented e-waste rules since 2012, with a shared responsibility model focusing on Extended Producer responsibility. The guidelines outline tasks for bulk consumers, including businesses, government bodies, educational institutions, and producers, excluding households. Government involvement is crucial in managing e-waste, as household usage of e-devices significantly increases volumes over time. Neglectful disposal behavior and environmental pollution result from negligent disposal. To address this, a participatory, structured system and current collection system development are necessary to reduce volumes and achieve economic benefits (Link 2016).

Pune Region Existing Model of E-Waste Management

Pune region generates considerably 10,000 metric tons of e-waste annually in the Pune region, and crucially, all of this operational trash ends up in landfills or scrap markets. The generators and collectors confuse e-waste with municipal solid garbage because they are unaware of the embedded worth of resources in it (Bhat & Patil 2021). Various stages of managing e-waste, including collection, separation, disassembly, reuse, reprocessing restoration, diffusion, and exposed burning/landfilling, are handled by reliable and connected informal sectors (Chhura & Kumar 2015). Therefore, a sketch of the present scenario of e-waste management is shown in Fig. 11. Lack of knowledge combined with a disregard for practical household appliances overlooks the risks that e-waste poses, which encourages irresponsible disposal practices. Despite the fact that homes contribute to the expanding amount of current e-waste, they must be carefully considered in e-waste management.

Pune, the second-largest producer of e-waste in Maharashtra, has been unable to effectively implement e-waste rules in the past four years. The region's proper segregation of dry and wet garbage contributes to proper waste disposal. However, a significant amount of e-waste ends up with informal collectors and recyclers, leading to resource loss and environmental degradation (Bhat & Patil 2021).

Households in the Pune region are significant stakeholders who might influence disposal behavior. Households that are well-informed and knowledgeable aid in the practice of systemic behavior and can aid in the management of sustainable e-waste management systems. Households receive monetary compensation from scrap merchants in exchange for their e-waste; however, products nearing the end of their useful life are diverted to the illegal market for dismantling or reconditioning. When they reach the point when continued use is no longer conceivable, a strong network of informal collectors

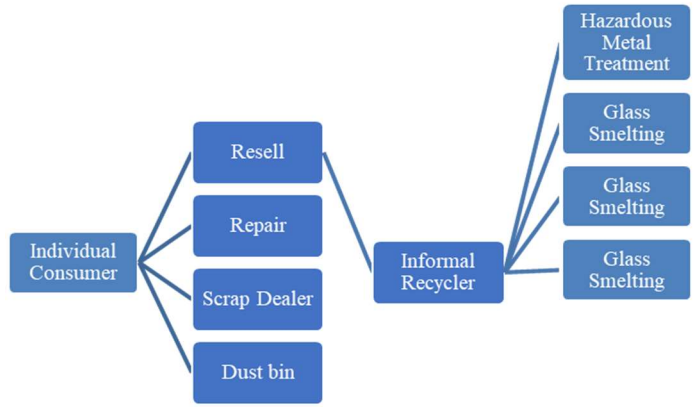

Fig. 11: Present scenario of E-waste management in Pune City (Bhat & Patil 2021).

guarantees their way to the informal recovering plants (Link 2016).

Inadequate collection arrangements by governing bodies have spread to the informal sector, leading to the use of existing e-waste management models. The Pune region model, a PPP model for efficient dry-wet waste management, has a significant gap in its scope, not including e-waste. The Pune region needs an efficient collection system for End-of-Life (EOL) items, with real-time data from generation to treatment and a convenient, accessible collection route. A low-cost method for recovering precious and hazardous metals is also crucial. The authors have developed a simple, low-cost Public-Private Partnership (PPP) model for managing household e-waste, integrating various processes for formal e-waste collection in response to current deficiencies (Bhat & Patil 2021).

CONCLUSION

The success of the Pune Municipal Solid Waste Management and SWaCH Model demonstrates that waste pickers are resourceful and adept at gathering and valuing resources and that partnerships between waste pickers and municipalities can benefit the environment, society, and economy. Pune's collection coverage could be enhanced, but lower-income groups may not be able to afford fees, and the city's structural composition may make it challenging to collect from all corners. Recovering valuable materials (including plastic) for regional and international recycling businesses directly supports a more circular municipal waste management paradigm. If the shift to a more formal circular plastic economy is to incorporate waste pickers and other non-formal actors, then investments must be made in the appropriate infrastructure, competencies, and capacities. The quantity of places and space made available for these decentralized activities closely relates to how much plastic garbage is collected and recycled in the city. To enhance plastic waste segregation efficiency and improve recyclable materials, municipalities should provide decentralized spaces for sorting and recycling, subsidized scrap shops, recycling hubs, waste collection systems, and locations away from environmental leaks. This will ensure better quality and a more sustainable waste management system.

The Red Dot Campaign is one of the most front-line approaches to sanitary waste segregation. It is easy to replicate the IEC program for sanitary waste separation. The success of PMC in reaching 2.14 million individuals (about 50% of Pune's population) serves as a model for other metropolitan local government entities. In terms of Pune's cleanliness and the dignity of rubbish pickers, citizens demonstrated a readiness to adopt the practice and recognized its significance. Municipal solid garbage is often untreated due to inadequate collection and treatment facilities. This is due to poor collection methods, lack of knowledge, and lack of source segregation. To address this issue, household-generated e-waste needs to be disposed of using a targeted and practical approach. Providing suitable doorstep MSW disposal infrastructure can change this behavior by extending the current segregation paradigm. For all urban local governments, integrating the unorganized sector and creating an organization like SWaCH is the way to go. It would not only assist in bettering waste management in cities but also lift the lowly and marginalized. It is crucial to educate the general people and informal workers about the dangers of disposing of plastic waste in the environment. To increase their sense of responsibility, it would promote an environmental identity inside the industry. As part of their extended responsibility necessities, producers should be urged to promote the improvement of the gray market recycling and scrap trade.

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