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DATA-DRIVEN WASTE MANAGEMENT: REVOLUTIONIZING MUNICIPAL SERVICES THROUGH DIGITAL INNOVATION

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ABSTRACT: *The exponential growth of urban populations worldwide has amplified the urgency for efficient waste management strategies. In response, this research pioneers a paradigm shift towards data-driven solutions for waste management, heralding a new era of digital transformation in municipal services. Through the development of a cutting-edge web application using PHP, citizens are empowered to actively engage in waste reporting, catalysing swift and targeted interventions by municipal authorities. Leveraging advanced data analysis techniques, this system optimizes waste collection routes, ensuring maximum efficiency and minimal environmental impact. By placing users at the forefront of the waste management ecosystem, this innovative approach fosters a culture of responsibility and sustainability. Furthermore, the integration of mobile technologies and real-time data collection mechanisms enhances the responsiveness and adaptability of the system to evolving urban dynamics. This research not only underscores the transformative potential of digital innovation in waste management but also provides actionable insights for policymakers and urban planners seeking to build resilient and sustainable cities of the future.*

KEYWORDS: *Data-Driven Solutions, Waste Management, Digital Transformation, Municipal Services, PHP Web Application, Urban Sustainability, Mobile Technologies, Real-Time Data Analysis.*

1. Introduction

"Join hands for a cleaner environment"

In the face of escalating urbanization and industrialization, efficient waste management emerges as a critical imperative for sustainable development. As articulated by the proverbial wisdom, "Let us keep our home clean," the need for effective waste management solutions becomes ever more pressing. Waste management encompasses a spectrum of activities spanning from collection to disposal, embodying a comprehensive approach towards environmental stewardship and public health. Failure to address this challenge precipitates dire consequences, including soil and land pollution, which imperil the very fabric of our ecosystem.

The contemporary urban landscape stands at a crossroads, where the quest for economic prosperity converges with the imperative of environmental preservation. The efficacy of waste management practices serves as a litmus test for a city's resilience and sustainability in the face of burgeoning population and industrial growth. Municipal councils bear the onus of managing solid waste, a responsibility that transcends mere administrative boundaries to touch upon the fundamental nexus between human activity and environmental impact.

Waste management is facing a challenge due to exponential population expansion and rapid urbanization, especially in emerging metropolises. The size of the problem emphasizes how urgently creative solutions must be implemented to streamline the processes involved in waste collection, transportation, and disposal. Specifically, inadequate waste management techniques not

only harm the environment but also provide serious health hazards, underscoring the necessity of prompt and efficient intervention.

The advent of mobile technology heralds a transformative era in waste management, offering a conduit for real-time data collection, analysis, and intervention. Mobile applications, leveraging the ubiquity of smartphones and the proliferation of high-speed internet connectivity, present a potent tool for revolutionizing waste management practices. As the global landscape witnesses a seismic shift towards mobile data traffic, the impetus for enhancing network infrastructure and accelerating mobile application development becomes increasingly pronounced.

In this context, this research endeavours to explore the convergence of data-driven solutions and digital innovation in waste management, epitomizing a paradigm shift towards a more sustainable future. Through the development of a sophisticated web application using PHP, empowered citizens can actively engage in waste reporting, thereby catalysing timely interventions by municipal authorities. By harnessing the power of data analysis and mobile technology, this study seeks to optimize waste management processes, fostering a culture of environmental stewardship and sustainable urban development.

2.Objective

The primary objective of this research is to pioneer a paradigm shift towards data-driven solutions in waste management, addressing challenges posed by the exponential growth of urban populations worldwide. Specifically, it aims to develop a sophisticated web application using PHP, empowering citizens in waste reporting and facilitating swift interventions by municipal authorities. Furthermore, it seeks to promote a culture of responsibility and sustainability among users, placing them at the forefront of the waste management ecosystem. Ultimately, the research aims to provide actionable insights for policymakers and urban planners to build resilient and sustainable cities of the future, leveraging the transformative potential of digital innovation in waste management.

3. Scope

The scope of this research encompasses the development and implementation of a data-driven web application for waste management, with a focus on optimizing municipal services and fostering sustainability in urban environments. The project involves the utilization of cutting-edge technologies such as PHP programming and advanced data analysis techniques to enhance waste reporting, collection, and disposal processes. Additionally, the scope extends to the exploration of potential integration of mobile technologies for real-time data collection and analysis, aiming to improve the responsiveness and adaptability of the waste management system to evolving urban dynamics.

4. Literature Review (Background)

The growing amount of solid waste poses a serious risk to the environment and human health, so immediate action is needed to lessen its negative consequences. Utilizing the most recent developments in mobile technology to improve solid waste management procedures has been the subject of several recent studies. Municipalities seek to effectively manage the difficulties presented by solid waste by promoting sustainable habits, increasing recycling rates, and streamlining waste collection through the integration of innovative mobile solutions. These technology developments open the door to more effective and ecologically friendly solutions by facilitating improved data collecting and monitoring as well as encouraging community involvement in trash management programs. Studies emphasize the importance of engaging waste

producers, who play a crucial role in solid waste generation, in the waste collection process. By involving waste producers, waste management systems can be more efficient and effective, thereby reducing environmental harm.

The development of mobile waste management applications represents a promising avenue for improving solid waste collection quality and reducing environmental impact. These applications leverage various mobile technologies to streamline waste collection processes and provide valuable tools for waste firms and local councils. Recent literature highlights the integration of essential and current mobile technologies into waste management systems, underscoring the potential for creating successful waste collection systems at the household level. By harnessing mobile technology, researchers aim to optimize solid waste collection practices and promote sustainable waste management solutions. [1]

According to the UN's 2030 Agenda, the literature emphasizes the growing significance of digital technology in the cruise industry's sustainable waste management. Prior research has emphasized the application of text-mining algorithms and sustainability disclosure frameworks to corporate sustainability analysis. The results highlight the need to accomplish environmental targets by investing more in digital technologies on board ships.

Scholars emphasize the need for holistic approaches, engaging both crew and cruisers in waste management processes. Despite advancements, challenges remain in accurately disclosing nonfinancial information. This study pioneer's empirical identification of best practices through sustainability reporting analysis, shedding light on industry trends and regulatory influences.[2]

This literature highlights the growing significance of IoT systems, especially those utilizing LPWAN technologies like LoRa, for smart city applications. Transitioning from ideation to realization requires well-defined project targets and objectives to guide development effectively.

For brief pilot investigations, there are benefits to using cutting-edge components like off-the-shelf sensor nodes and LoRaWAN industrial gateways. These elements reduce development time and expenses while facilitating quick prototyping.

Agile methodologies are crucial for successful IoT deployments, emphasizing fast development cycles and minimum redundant tasks to maintain agility. Case studies focusing on entrepreneurial business development aspects provide valuable insights into practical challenges and opportunities in IoT deployment. In summary, clear project targets, advanced components, agile methodologies, and case studies contribute to successful IoT deployments in smart cities, fostering adaptability and scalability in real-world environments.[3]

The convergence of Internet of Things (IoT) and Industry 4.0 technologies is revolutionizing manufacturing processes, enabling real-time data collection and analysis for enhanced decision-making and production optimization. Recent studies highlight the integration of IoT solutions with data analytics and modelling techniques to facilitate predictive maintenance and automated waste management in manufacturing settings. These solutions leverage sensor data to detect abnormalities and predict maintenance needs, thus minimizing downtime and maximizing equipment efficiency.

In particular, vibration sensors are utilized for predictive maintenance in key plant equipment, allowing for the early detection of abnormal vibrations. Smart fill level sensors are also deployed for industrial bins, enabling real-time monitoring and notifications based on sophisticated statistical methodologies.

Furthermore, the development of a Digital Factory Model (DFM) based on standardized formats facilitates interoperability and data exchange within manufacturing environments. This enables the creation of live factory instances containing sensor data and analytics tools output, fostering a more integrated and efficient manufacturing ecosystem.[4]

In industrialized nations, worries about construction waste management have increased due to the boom in urbanization and infrastructure development projects. Recent research, with an emphasis on nations like Australia, Canada, the United Kingdom, and the United States, highlights the necessity of addressing recycling and reuse strategies for trash from building and demolition.

Scholars employ novel metrics, query-based searches, and social network analysis techniques to evaluate a dataset of publications spanning a decade. This approach identifies key authors, influential universities, collaboration patterns, and research trends within the construction waste management domain.[5]

Current research primarily emphasizes concrete waste, while other commonly used building materials like glass, brick, steel, and wood receive little attention. Despite some progress, there is a scarcity of literature addressing the incorporation of Geographic Information Systems (GIS), Building Information Modelling (BIM), 3D printing, and geo-spatial data analysis in the context of waste management within the construction industry.

University networks in Canada and the US demonstrate stronger domestic collaboration and industry partnerships compared to those in Australia and the UK. Publications involving industry co-authors are more likely to address regulatory issues, indicating the importance of industry-academic collaborations in shaping waste management practices.

The findings underscore the need for future research to address gaps in the literature, improve industry collaborations, and harness information systems for more effective construction waste management strategies. This holistic approach aims to guide academics, engineers, and regulators in predicting research trends and allocating resources to address identified gaps effectively.[6]

The management of electronic waste (e-waste) plays a crucial role in promoting environmental sustainability, yet there remains a gap in understanding the awareness levels and practices surrounding e-waste management, particularly in educational institutions. Recent studies have sought to address this gap by investigating the awareness levels and practices of e-waste management among engineering students in India. Empirical studies utilizing well-structured questionnaires have been conducted to assess six critical aspects of e-waste: generation, management, nature of e-waste components, progressive use of e-waste management, control, and training. These studies aim to shed light on the current state of e-waste awareness and management practices among engineering students.[10]

Findings from these studies reveal deficiencies in the awareness levels of e-waste generation and processing practices among respondents. However, there is a growing influence of the extended producer responsibility concept, indicating a shift towards more responsible e-waste management practices. Despite efforts by competent authorities, only a small portion of the population demonstrates awareness of e-waste management. However, respondents exhibit awareness of the hazardous effects of e-waste and recognize the potential for its progressive usage. Furthermore, there is a strong desire among prospective engineering graduates for the inclusion of e-waste management in study programs, highlighting the importance of integrating e-waste education into engineering curricula to foster a more informed and responsible generation of professionals. [7]

5. Methodology

5.1. Logic and Need of Application

India is facing serious environmental problems as a result of insufficient trash management, transportation, treatment, and generation. There are serious consequences for the environment and public health in India as a result of the current system's inability to handle the country's growing

urban population's garbage production. It's critical to understand that these challenges present chances for development. It is critical for environmental preservation and sustainable development to give priority to waste management systems that effectively handle precious resources rather than depending on ineffective trash dumps. Effective management of residual waste can be achieved by making investments in waste-to-energy plants and well-planned landfill sites. Although thermal treatment or methane extraction can be used to recover energy from landfills, India lacks qualified environmentalists and engineers with experience in improving waste management systems.

The worldwide waste management sector has historically adopted new technologies slowly. But things are changing as the sector finds creative ways to deal with the waste problem and pollution in the environment. For example, smart dumpsters are being used in numerous locations across the globe. However, the public's awareness of and participation in environmental conservation initiatives is crucial to the effectiveness of such solutions. People must so be inspired and educated about the value of recycling and waste management. Furthermore, it's critical to set up channels for informing the community about new waste management programs and solutions.

Applications for recycling and trash management are useful in this situation. These applications help users manage their garbage more efficiently by acting as information centers for waste management. Our solution takes use of the fact that consumers today rely largely on their mobile phones for a variety of functions. Our online application is designed to automate trash management procedures. It is developed with PHP and stores user login credentials and rubbish data in PhpMyAdmin and MySQL. Our user-friendly mobile application interface makes it simple for users to submit their household waste. The admin can access and evaluate the reported complaints in the PHP database to determine the status of the complaint and take appropriate action. Our goal with this digital platform is to enable people to take an active role in trash management initiatives and help create a cleaner, healthier environment.

5.2. Research Setting

In India, rapid urbanization and increasing per capita income have led to a significant surge in municipal solid waste generation. Over recent years, electronic and plastic waste have become major contributors to the overall waste stream. The outbreak of the novel coronavirus disease (COVID-19) pandemic further exacerbated the issue, resulting in a substantial increase in domestic hazardous and biomedical waste. Improper disposal of these materials poses serious risks to human health and the environment. According to a 2014 Planning Commission report, urban India produces approximately 62 million tonnes of municipal solid waste (MSW) annually. Projections indicate that by 2030, this volume is expected to skyrocket to 165 million tonnes.

Furthermore, the digital transformation presents an opportunity to revolutionize the waste management sector, impacting costs, environmental sustainability, and social dynamics. Few industries are as closely connected to the development of the circular economy as waste management, highlighting the potential for innovation and improvement in this domain.

5.3. Methods and Procedures for Data Collection

Effective research hinges on the meticulous collection of data, which can be classified into two main categories: qualitative and quantitative. While qualitative data pertains to textual information, quantitative data consists of numerical values. Given the mixed-method approach employed in this study, both qualitative and quantitative data were deemed essential.

To gather qualitative insights, semi-structured interviews and non-participant observation methods were employed. Semi-structured interviews allowed for a flexible yet focused approach to capturing diverse perspectives, while non-participant observation facilitated firsthand observation of waste management practices and community behaviours.

For quantitative data collection, a unique approach was adopted using a digital waste reporting platform. This platform enabled users to submit reports and complaints regarding waste management issues, providing real-time quantitative data on the frequency and nature of waste-related concerns. Additionally, data analytics tools were utilized to analyze trends and patterns in waste reporting, enhancing the understanding of waste management challenges and opportunities. By combining these innovative methods, the research ensured comprehensive data collection, enabling a holistic analysis of waste management dynamics and facilitating informed decision-making for sustainable solutions.

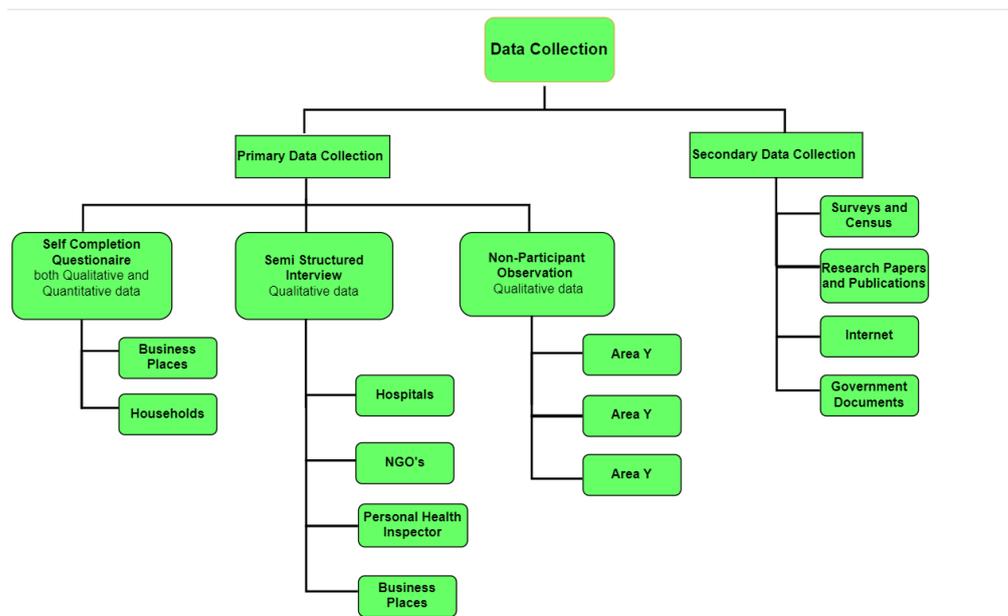


Figure 1: Different Methods of Data Collection

5.4. METHODOLOGY FOR WMS

Problem Identification and Research

Identify the challenges and inefficiencies in waste management in Chennai, focusing on solid waste generation, collection, transportation, treatment, and disposal. Conduct thorough research on existing waste management systems, technologies, and best practices.

Requirement Gathering and Analysis

Collaborate with stakeholders including municipal authorities, waste management experts, and environmentalists to understand the specific needs and requirements for the WMS. Analyze data related to waste generation, collection efficiency, current disposal methods, and public complaints regarding waste management.

System Design and Architecture

Design the architecture of the Waste Management System using PHP for backend logic and

MySQL for database management. Develop a user-friendly interface for the municipality complaint app to allow citizens to report waste-related issues and track the status of their complaints.

Development and Testing

Develop the WMS platform, including modules for waste complaint management, location tracking, work status updates, and reporting. Implement security measures to protect user data and ensure system integrity. Execute thorough testing that encompasses unit testing, integration testing, and user acceptance testing to ensure the system's functionality and performance are validated.

Deployment and Training

Deploy the WMS platform on a secure server accessible to municipal authorities and citizens. Provide training sessions for municipal staff and users on how to use the WMS effectively for waste management activities and complaint resolution.

Monitoring and Maintenance

Monitor the system regularly to ensure smooth operation, address any technical issues, and incorporate user feedback for continuous improvement. Regularly update the system with new features, optimizations, and security patches as needed.

The figures below illustrate the functionality of the Green Earth Waste Management System Web Application, detailing both user and admin functionalities through use case diagrams.

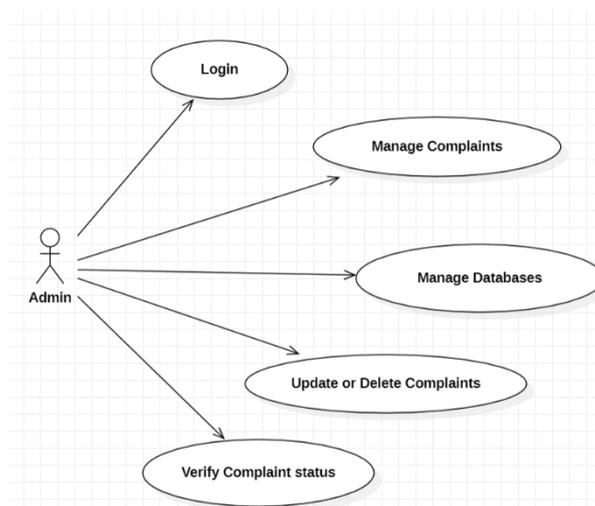


Figure 2: Use Case Diagram for Admin

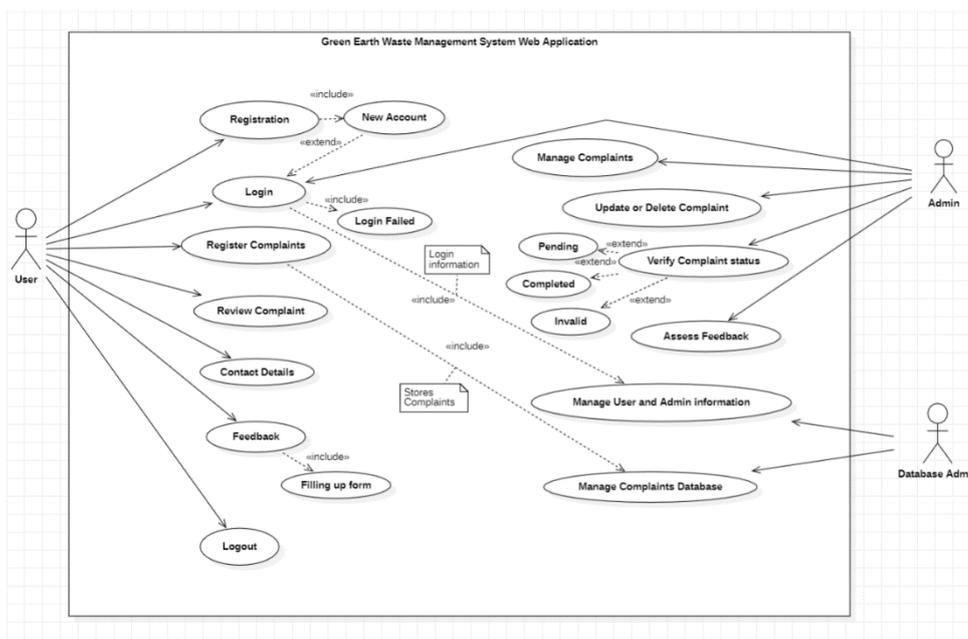


Figure 3: Use Case Diagram for the Green Earth Waste Management System

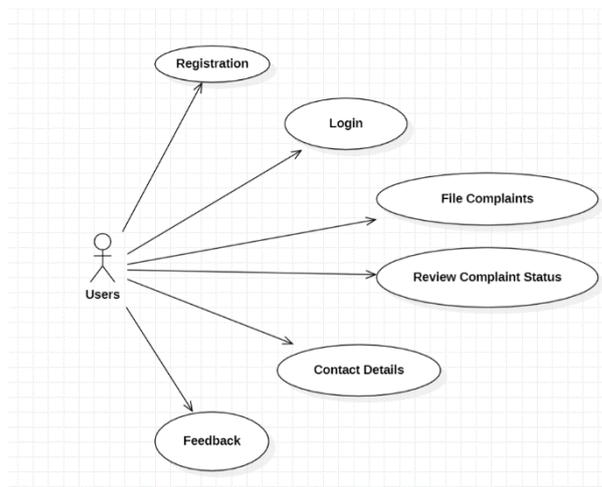


Figure 4: Use case diagram for User

5.5. Technologies Used

For the web application of our waste management system, we employed the following technologies:

XAMPP: XAMPP is a free and open-source cross-platform web server solution stack created by Apache Friends. It includes the Apache HTTP Server, the MariaDB database, and interpreters for scripting languages such as PHP and Perl. XAMPP streamlines the setup of a local server environment, making it easier for developers to carry out testing and development tasks.

PHP: PHP is a server-side scripting language widely used for web development. It is particularly well-suited for integrating dynamic content into web pages and interacting with databases. In our waste management system, PHP serves as the primary backend language for handling user requests, processing data, and interacting with the MySQL database.

MySQL: MySQL is an open-source relational database management system (RDBMS) that provides a robust and scalable solution for storing and managing structured data. In our application,

MySQL is utilized to store various data related to user information, waste complaints, and administrative records.

PhpMyAdmin: PhpMyAdmin is a free and open-source web-based administration tool for managing MySQL databases. It offers an intuitive graphical interface for performing tasks such as database creation, modification, and querying. We utilized PhpMyAdmin to interact with the MySQL database, facilitating efficient database management and administration tasks.

By leveraging these technologies within the XAMPP environment, we were able to develop and deploy a robust web application for waste management, ensuring seamless functionality and efficient data management capabilities.

6. Results and Discussion

Table-1: Types of Solid Waste Generated

Waste Type	Percentage Composition (%)
Organic Waste	45
Paper and Cardboard	20
Plastics	15
Glass	5
Metals	5
Others (e.g., e-waste)	10

The composition of solid waste generated, categorized by waste type and their respective percentage compositions. This table provides insights into the distribution of various types of solid waste commonly encountered in waste management systems. [9]

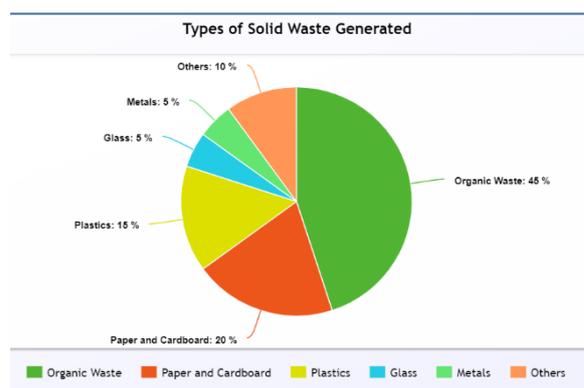


Figure 1: Types of Solid Waste Generated

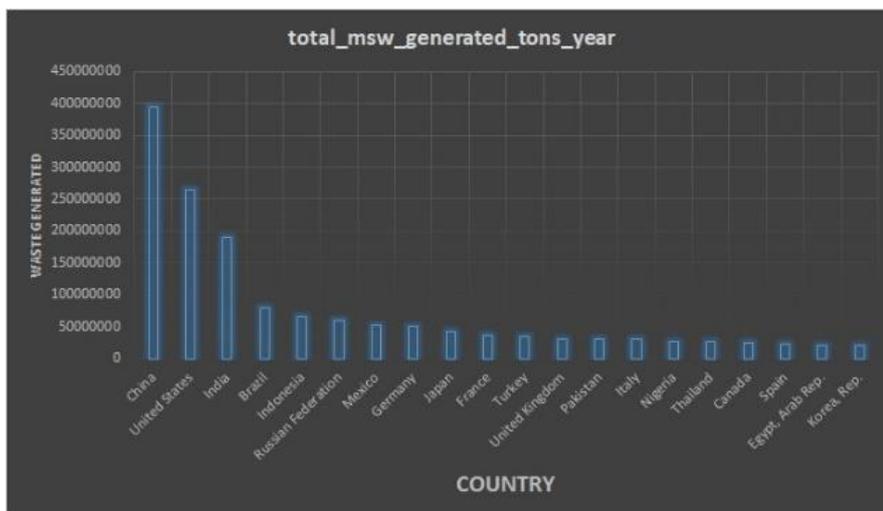


Figure 2: Total solid waste generated in a year (in Tonnes)

This bar chart provides a clear and intuitive way to convey the conclusions drawn from the data on total MSW generation for various countries. It helps viewers grasp key insights at a glance and facilitates informed discussions on the importance of sustainable waste management practices at both the national and global levels. [10]

Table-2: Waste Generated and Processed Statewise (in Tonnes per day)

Sl. No.	State/UT	Waste Generation (in TPD)	Waste Processed (in TPD)
1	Chandigarh	526	526
2	Chhattisgarh	1645	1645
3	Madhya Pradesh	6678	6669
4	Delhi	10181	9398
5	Gujarat	9942	9139
6	Telangana	10238	9404
7	Karnataka	9514	8654
8	Andaman and Nicobar Islands	52	47
9	Maharashtra	25296	22514
10	Andhra Pradesh	6604	5681
11	Uttar Pradesh	18020	15361
12	Odisha	1745	1447
13	Goa	175	142
14	Uttarakhand	1552	1251
15	Manipur	221	176
16	Himachal Pradesh	430	340
17	Jammu and Kashmir	705	534
18	Kerala	2131	1598
19	Haryana	5650	4042
20	Assam	1141	808
21	Tamil Nadu	14372	9776
22	Tripura	103	70
23	Daman and Diu	81	54

24	Punjab	3579	2326
25	Jharkhand	2156	1342
26	Ladakh	17	10
27	Rajasthan	6172	2537
28	Sikkim	71	25
29	Arunachal Pradesh	242	77
30	Bihar	6106	1306
31	West Bengal	7876	786
32	Puducherry	381	35
33	Nagaland	37	2
34	Meghalaya	3	0
35	Mizoram	176	0

While some states showcase commendable waste management practices, there remains significant scope for improvement across the board. Addressing the identified challenges and capitalizing on opportunities for enhancement can play a pivotal role in fostering more sustainable and efficient waste management systems nationwide.

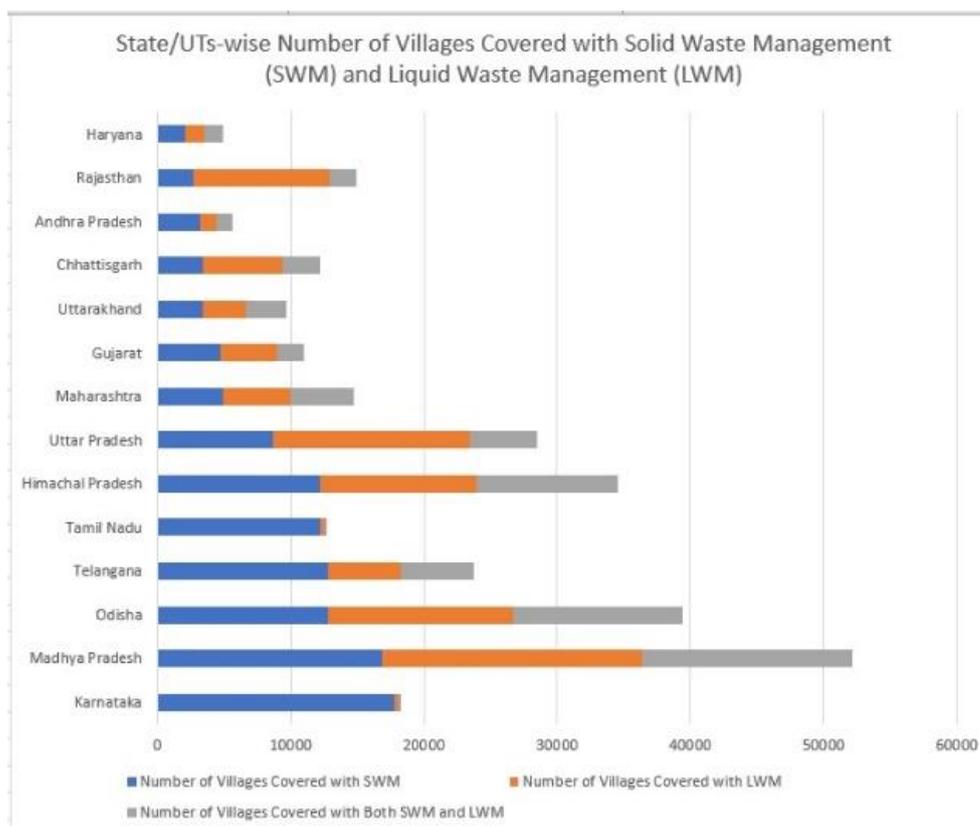


Figure 3: State/UTs-wise Number of Villages Covered with Solid Waste Management (SWM) and Liquid Waste Management (LWM)

The above graph illustrates the state-wise distribution of villages covered with Solid Waste Management (SWM) and Liquid Waste Management (LWM) across different States and Union Territories (UTs). Each bar represents the number of villages covered with SWM and LWM in a particular State or UT.

Table-3: Recycling Rates

Waste Type	Recycling Rate (%)
Organic	60
Paper	70
Plastic	40
Glass	80
Metal	90

This table presents the recycling rates for different types of waste, expressed as percentages. The recycling rate indicates the proportion of each waste type that is successfully recycled or diverted from disposal in landfills or incinerators.

Organic Waste: This category includes biodegradable materials such as food scraps and yard waste. The recycling rate for organic waste is 60%, indicating that 60% of organic waste is effectively recycled or composted rather than being disposed of as waste.

Paper: Waste materials derived from paper products, including newspapers, cardboard, and office paper, have a recycling rate of 70%. This suggests that 70% of paper waste is recovered and recycled into new paper products.

Plastic: Plastics, which are non-biodegradable synthetic materials widely used in packaging and consumer products, have a recycling rate of 40%. This means that 40% of plastic waste is recycled into new plastic products or other materials.

Glass: Glass waste, including bottles and jars, has a high recycling rate of 80%. The majority of glass waste is collected and recycled into new glass products, reducing the need for raw materials and energy in glass production.

Metal: Metals, such as steel, aluminum, and copper, have the highest recycling rate among the waste types listed, at 90%. This indicates that 90% of metal waste is recovered and recycled into new metal products, contributing to resource conservation and energy savings.



Figure 4: Green Earth Waste Management System Web application

The web application's home page, shown in Figure 4, offers customers a simple interface via which they can effortlessly access its range of services. With this design, users can access all functionalities with ease and are guaranteed a user-friendly experience.

Figure 5: User Complaint form

The Complaint Form, shown in Figure 5, allows consumers to file or record complaints about garbage collection. The user can designate the type of garbage, such as Organic garbage, Inorganic Waste, Household Waste, or All, by filling out fields on the form for their name, mobile number, and waste category. Users also have the ability to upload a picture and are needed to enter the location of the waste. After finishing, consumers can file a complaint straight through the website, guaranteeing prompt communication with local government services.

Figure 6: Users Complaint Edit form

The User Complaint Edit Form, shown in Figure 6, enables users to edit and resubmit previously submitted complaints. This feature makes sure that the user can easily make any modifications or adjustments to the complaint.

Id	Images	Date	Name	Mobile	Email	Waste Category	Location	Location Description	Status	Action	Update status
102		9 11pm, Wednesday 20th March 2024	janak bist	9848726051	bistajanak303@gmail.com	mixed,	Klm	Pulchowk campus	Completed	Delete	Status
105		9 11pm, Wednesday 20th March 2024	janak bist	9848726051	bistajanak303@gmail.com	inorganic,	Bktpur	bhaktapur durbar square	Completed	Delete	Status

Figure 7: Admin Dashboard

The Municipal Admin Dashboard, shown in Figure 7, displays every complaint that has been registered by a user. Administrators may keep an eye on each complaint's status with this dashboard, which indicates whether it is pending or closed. The dashboard also offers choices for the municipal team to respond appropriately to every complaint, guaranteeing prompt and effective issue resolution.

7. Conclusion

In conclusion, the advent of data-driven waste management represents a significant leap forward in revolutionizing municipal services through digital innovation. This research underscores the transformative potential of leveraging advanced technologies to address the pressing challenges of waste management in rapidly urbanizing environments. By developing a cutting-edge web application using PHP, citizens are empowered to actively engage in waste reporting, catalyzing swift interventions by municipal authorities. This not only makes waste collection and disposal procedures more efficient, but it also encourages a sustainable and responsible culture among users.

Furthermore, the integration of mobile technologies and real-time data collection mechanisms enhances the responsiveness and adaptability of the waste management system to evolving urban dynamics. This innovative approach not only optimizes resource utilization but also ensures minimal environmental impact, contributing to the creation of resilient and sustainable cities of the future.

In essence, data-driven waste management represents a paradigm shift in municipal services, offering actionable insights for policymakers and urban planners to build more efficient, responsive, and sustainable urban environments. By embracing digital innovation, we can pave the way for a cleaner, healthier, and more prosperous future for all.

8. Future Scope

Subsequent studies may investigate the integration of location services with digital maps to augment the efficacy of the waste management infrastructure. Users could receive automated alerts and messages based on when waste is collected, and real-time tracking could simplify processes to enable better management and a prompter reaction to waste-related problems.

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