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An IoT-based waste management approach for environmental sustainability

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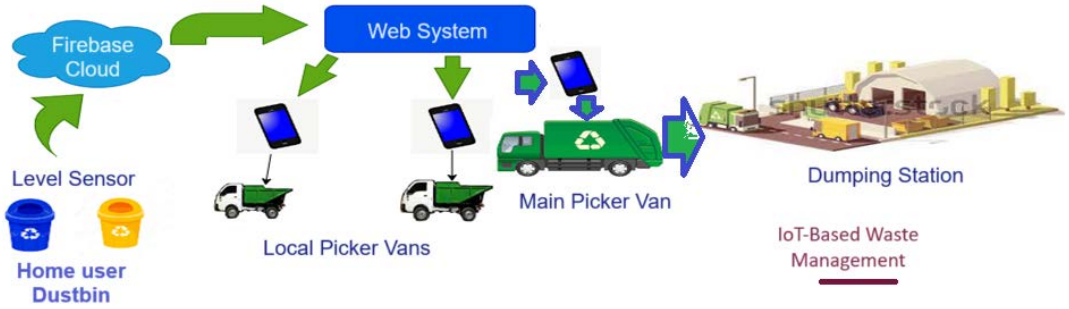
ABSTRACT



Solid waste management affects everybody. Government and individual waste and consumption decisions effect efficiency, health, and cleanliness. Poor waste management pollutes oceans, sewers, and floods, affecting humans and nature. BHARAT ABHIYAAN and tech-driven Smart trash Management reduces trash in many developing nations. Communities learn trash management via IoT-based smart garbage management in this research. Garbage collection automation should help. Pune Municipal Corporation IoT solution. Our technique is better since we analyzed all Android and Web app-using waste management providers, including homes, trash trucks, and disposal sites. Waste management will improve with 360^0 automated systems.

Keywords: Waste Management, Dry Waste, Wet Waste, IoT Devices, Android, Automation

INTRODUCTION

The growing consumption of packaged items, textiles, paper, plastics, food, vegetables, glass, metals, and other substances as the population grows and family units become more common, leads to increase in the quantity of waste produced daily by sectors and families at a rapid pace.[1] Thus, managing waste has become an essential part of our everyday life in most industrialized nations; there are numerous efficient strategies for appropriate garbage management; However, in some developing nations, people are casual about keeping their surroundings clean, and there are several issues, such as a lack of severe requirements for using materials that are recyclable, adequate environmental policies, and laws for equitable growth. The public bins used for collecting trash are full and the neighborhood is cluttered, resulting in not only odorous roads but also a significant influence on wellness and the natural world.[2] Waste is a serious problem that must be tackled with prudence. We separate our rubbish at home to make processing and recycling easier. We saw that garbage trucks seldom arrived at households, resulting in domestic despoliation.[3] As a consequence, many individuals empty their garbage cans in public places leading to worsening of environmental pollution. Waste is a major source of concern for both humans and the environment, with a wide range of adverse effects.[4] Trash serves as a breeding habitat for insects, diseases, and flies, such as those that fly over delicacies and drop their offspring. As a result, they raise the risk of food poisoning, typhoid, diarrhoea, and salmonella, as well as the insects that cause dengue and malaria fever. Aside from flies and insects, other species that thrive on rubbish include rats and stray dogs, which spread illnesses. Garbage also causes various respiratory disorders, as well as harmful contaminants such as CO_2, nitrous oxide, methane, and so on.[5,6] Waterborne hazardous waste, such as electrical devices and plastic bottles, has an influence on aquatic species and, indirectly, people. Garbage cans that are overflowing are also a public annoyance and an eyesore. Everyone loves to visit cities that are clean and fresh. A dirty city with garbage all throughout does not entice visitors, resulting in wasted money and opportunity.[7]

From 1901 to 2017, the city of Pune's population grew substantially, putting a strain on the Pune Municipal Corporation's garbage treatment infrastructure. One of the major sources of waste is the waste collected from households. The Household level waste

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is increasing day by day which consists of Dry, Wet and other mixed type of waste (biodegradable, Electronic, concrete[8]) etc. Additionally, the water content is too big for garbage, necessitating the need of additional fuel for incineration.[9] Figure 1 shows the waste segregation of the PMC area from the household.

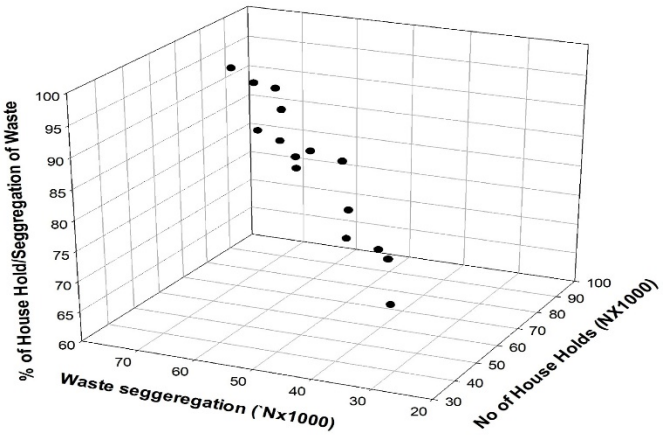


Figure 1. PMC % of waste segregation in households

Figure 1 depicts the amount of residential and domestic garbage collected. That data is 100% property-wise trash collection and details on every day's garbage delivered to the waste pickers is insufficient and has an influence on the city's noisy environment and aesthetic viewpoint. Furthermore, rubbish collected from the edges of roadways and street sweeping is growing at the ward level.[10]

The following are some of the primary reasons for 100% local solid waste collection at the door. It is critical to collect primary garbage on a daily basis and to identify the origin of the waste collection.

1. Every day, waste is thrown to Chromic Sites.
2. Inconsistency in garbage user fee collection.
3. Citizens' laziness causes daily rubbish to go uncollected.
4. The collecting of common items in a multi-storage complex was not done adequately.
5. The office time and the daily waste collection time aren't the same.
6. At the home level, waste is not separated.
7. Waste from many days will be kept in a plastic bag.

S.C. Patil and M.R. Gidde[11] carried out a one-year study in the Pune Municipal Corporation area, involving field visits to 7 transfer centres and 15 ward officer interviews, with different factors contributing to 100% door-to-door collection of separated Municipal solid waste present challenges and sustainable solutions to the aforementioned smart waste management problem. Collecting can be improved by installing soft computers for collecting, a better waste segregation methodology, and setting up processing facilities at the ward level. By fostering citizen participation in the system for handling waste.[11] The study emphasises the present stage and future scope of techniques.

We chose to design a Smart IoT-based trash Management System built on Android and web apps since the existing trash management procedure for Pune Municipal Corporation has limits and causes.[12] The uniqueness of our system is that we are creating a separate interface for Users, Waste Pickers and Administrators at the central dumping station which makes it beneficial to get a complete overview of the waste collection management system. The home users as well as industry users will be given a unique RFID card (Radio Frequency Identification Card) through which they will deposit the waste in the allotted dustbin and daily/weekly/monthly monitoring will be done on this by the administrator[13]. Failing to do so we had also made provision to charge fines to the home users and industrial users which will make some kind of discipline to citizens. Through this system, we are trying to achieve 100% waste management for Pune City.

Taking into account the previously mentioned current solid waste collection issues in the Muncipal Corporation territory, the purpose of this research is to suggest an effective approach for 100% Door 2 Home Solid waste management utilising a Smart IoT kit. The following represent a few of the research objectives.

100% Door to Door Solid waste management with effective implementation using IoT Kit.

1. Encouraging every household and end user to dump the waste on daily basis.
2. Generating various reports to understand the waste collection process.
3. Smooth and effortless execution of entire solid waste management through various entities of the system like Users, Waste Picker Van, Dumping station.
4. Remotely managing all activities through central dashboard of system.

RELATED WORK

Smart waste management is one of the most visible IoT-based services available in smart cities. Because of the vast population and urban regions, proper garbage disposal services are difficult to provide. Because of the vast population and urban regions, proper garbage disposal services are difficult to provide. Inadequate trash disposal, a lack of regular waste collection and management systems, and inadequate processes have resulted in serious environmental difficulties and high disposal costs. Improper disposal of trash, a lack of consistent collection and organisational systems, and inadequate processes have resulted in significant environmental difficulties and exorbitant waste removal expenses.

Tripathi et al. (2020)[14] developed a two-wastebasket smart waste basket idea for smart cities. This will keep garbage out of landfills. Ashvin al., (2021)[15] studied a cloud-based trash monitoring system powered by small solar panels in order to render the unit more environmentally friendly. In order to enhance waste pickup routes in cities, Bharadwaj et al., (2017)[16] devised an IoT-based system that checks garbage levels in household waste bins and transfers data to a server. The researchers Sheng et al., (2020)[17] employ LoRa technology for communication to warn garbage collection equipment when waste containers are full. There are multiple garbage cans situated throughout city, which are outfitted with low-

cost on-board electronics that allow the levels of the waste containers to be monitored.

Sensor-enabled smart bins linked by a cellular network capture massive amounts of data, which is then analysed and presented in real time, providing light on the city's rubbish management issue. Jheng et al. (2019)[18] provided smart transportation protocols for monitoring systems that included flow control and a synchronised mechanism to increase system efficiency.

The system uses IoT via tags with RFID and ultrasonic detectors to monitor and quantify local interest in WMS. Ramsan et al., (2021),[19] researchers presented an automated system for material recycling segregation, with a recycling container loaded with four various types of sensors, namely inductive sensors that are used for recognising plastic, capacitive detectors used to detect metal, photoelectric sensors utilised to detect paper, and proximity detectors used to monitor motor position.

Das et al., (2021)[20] investigated international medical solid waste management methodologies, identified challenges associated with global clinical solid waste management, and provided solutions to these concerns. It also gives vital insights into medical waste disposal options throughout the COVID-19 outbreak, in addition to a viable road forward. Rangaranjan et al. (2020)[21] proposed a smart trash disposal system with a successful routing method that use ERS methods to mitigate data transmission latency by considering one of the essential QoS criteria.

According on the findings of the previous study, researchers have developed a variety of connected to the internet of smart waste management strategies for intelligent towns and cities. The waste management system suffers if garbage bins in impacted regions fail to be emptied at regular intervals. The local authority fails to collect this garbage on a regular basis, resulting in a host of health issues. Naturally, everything is not just the duty of the local government; people have equal responsibilities for regular waste management. Citizens should be informed and penalised accordingly in order to develop a proper framework for smart trash management on a regular basis. The analysis of current smart trash disposal systems indicates that present cleaning procedures fail to keep up with the rate at which the bins in the city's various ward regions fill up, showing the necessity for such SMART IoT-based daily garbage collection, which pushes us to continue this research proposal.

METHODOLOGIES

The smart waste management application with 100% door-to-door waste picking was designed and developed using IoT with web and Android technologies.[22] Our goal is to give a user-friendly application for household users, waste pickers, drivers and dumping station admins. The application is broadly classified into 2 ways

1. An Android-based mobile application for users for dropping waste in dustbins. The drivers and waste pickers will also use the same Android application for the collection of waste and tracking the route of the ward wise.
2. The web application is majorly for the dumping station admin which will help the Municipal Corporation to manage and administrate the waste picked up as well as to track the user defaulters. Various reports will be generated from the Management Information Services (MIS) perspective like day-wise collection, dry/wet collection etc.

Figure 2 illustrates our smart waste management system's overall system block diagram

THE HARDWARE INTERFACE

GSM, and GPS modules along with an Arduino Uno kit for understanding the level of the dustbin placed near the home users[13]. Every home user will be given a unique RFID card after registration

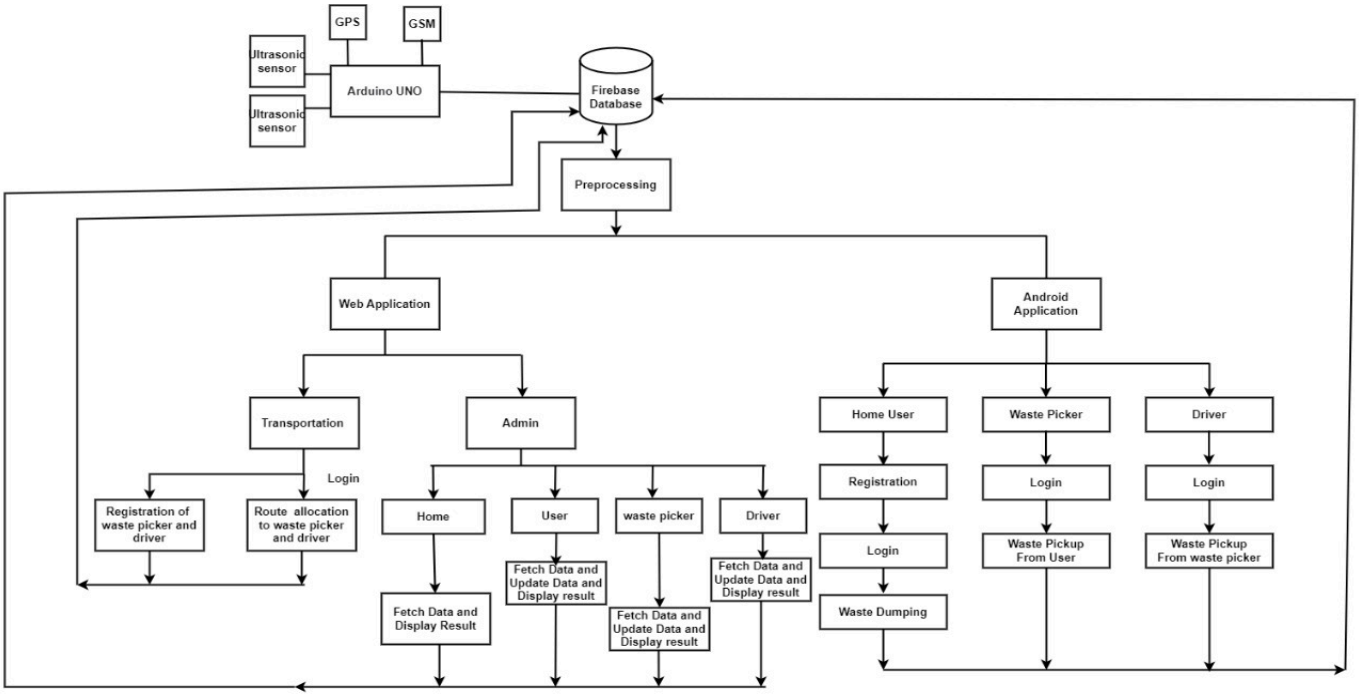


Figure 2: Block Diagram of Smart Waste Management System

in our system. Figure 3 shows the hardware interface kit designed for our system.

Every hardware kit consists of two ultrasonic sensors to identify the garbage level of dustbins. One ultrasonic detector is used for dry garbage, while the other is used for moist waste. The kit consists of an Arduino Uno ESP processor which was programmed explicitly in C language.[13] The home users will be dumping their waste in respective dustbins. The ultrasonic sensors will be sensing the level of the respective dustbins and with the help of GSM and GPS modules, they will be uploaded the data into our cloud-based database[23]. We used the Firebase database for our application as it has great compatibility with Android applications and it also has the advantage of real-time data upload.[24] Figure 3 shows the hardware kit provided for the home users. The waste pickers who also got a login to an Android app will be visiting the allocated route and they will be provided hardware kit. The waste picker will visit door-to-door in the allocated area and the waste picker will be picking the waste from home users daily based on the level of the dustbin. We had kept an 80% threshold for dustbin level and as mentioned earlier, the Firebase database gives real-time data, the moment the dustbins are more than 80% garbage, the alert will be sent to waste pickers to collect the garbage from respective home users.

Figure 3: The Smart Waste Management Kit provided to Home Users

WASTE PICKERS VANS

A further part is then carried out by the waste picker's vans. These are our garbage vans which will be sent by the admin based on levels of garbage collected by waste pickers on a particular route. The driver will be getting an alert again with the same Android app which we had designed for our smart waste management system. They will be having their login to understand various things like route allocated, level of dustbins etc.

The waste picker vans will collect the dry and wet garbage from a particular route allocated and once their van gets more than the 80% threshold the admin of the system will get an alert in their web application to understand on which route the waste collection is completed. Accordingly, they can manage the process at the dumping station.

For the whole admin control of our smart trash management, a separate web application was created utilising HTML, CSS, and JavaScript, as well as the Firebase database. It majorly contains two modules as per the following description

ADMIN MODULE

The admin of our web-based application is assigned at the main dumping station of the Municipal Corporation. He is the sole controller of our system. He can get a view of an entire system in one glance as we had provided a dashboard for the admin to manage all operations of our system. The major task which is getting performed by admin is as follows

1. Authentication of all types of users (Home, Driver, Waste Pickers)
2. Fetching data from time to time from real-time Firebase database and
3. Generate various reports for analyzing and controlling smart waste management to ensure 100% door-to-door waste pickup.

All the above reports and results will be discussed in section 3 of the results and discussion.

TRANSPORTATION MODULE

The web application design also consists of the transportation module which specifically focuses on the waste pickers and drivers.

The major activities which are getting carried out by the transportation modules are as follows:

1. Registration of Waste Pickers and Drivers
2. Route allocation to waste pickers and drivers.

FLOWCHART OF THE SYSTEM

This section discusses the Flowchart used in our web application and Android application module. Figure 4 gives an insight into the flowchart of our system.

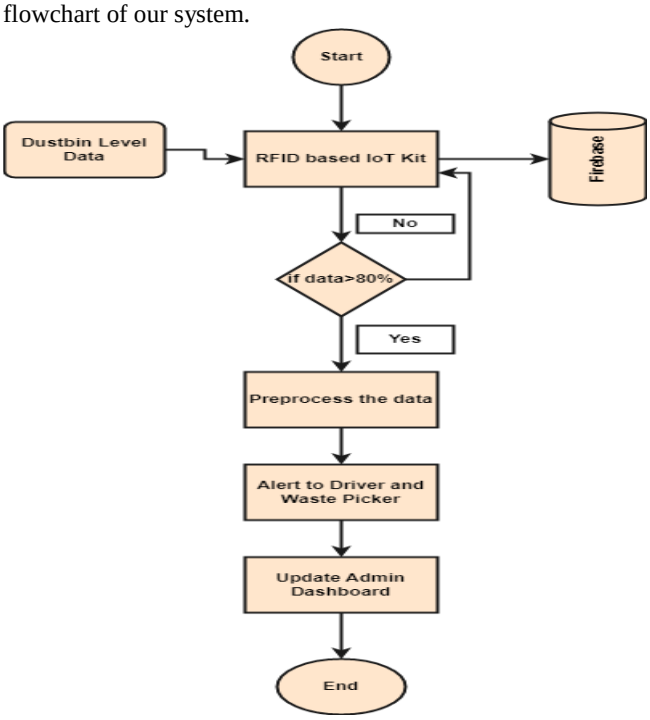


Figure 4: Flowchart of the system

RESULTS AND DISCUSSION

PLATFORM EXPLANATION

We will go through the results of our smart waste management system in this part. In this section, we will go over the outcomes of our smart system for handling waste. As our objective is to collect 100% door-to-door waste collection, our system designed and developed achieves it by giving proper notification and defaulters list of users who are not regularly putting their wastes in their respective dustbins.

Figure 5 represents the dashboard of the admin of our system for smart waste management. Once the admin logs in to the system, he/she will be able to visualize the system at once glance with proper pie charts for daily collection of waste based on the waste picker, route-wise and drive-wise. Along with this he/she can monitor the number of active home users, drives and waste pickers on duty daily.

We also develop the user page which admin can visualize. Here the admin can visualize the user's waste level daily. This is a very important report in our system as it gives a glance at whether the user is active or not for dumping his/her waste in the dustbin. The daily report can be seen by the admin for that particular user along with total waste collection, total waste treatment, and total waste disposal done so for every user. This is one of the important pages which help to achieve 100% door-to-door waste management. The alerts will be sent to the users by the admin if he frequently fails to dump the waste in the dustbin. We will be also making provision for users to make some fine in rupees if he fails to deposit the waste in the dustbin.

Our system also gives the facility to export various reports into Excel for further management of MIS reports for analyzing the data. The different reports which can be exported are as follows:

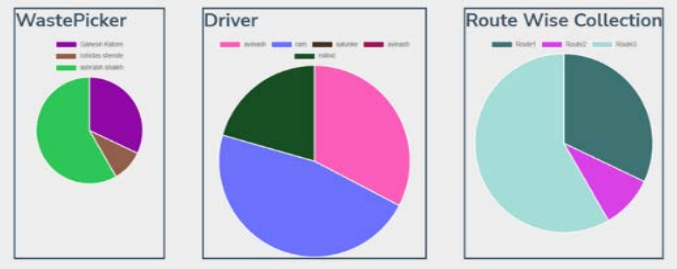
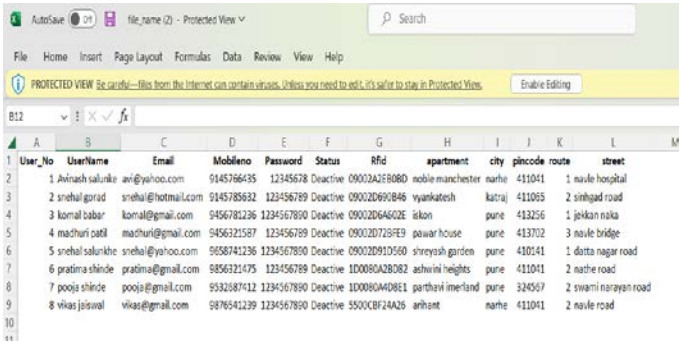


Figure 5: Dashboard

1. Day-wise waste collection report
2. Route-wise waste collection report
3. User availability report
4. Driver availability report
5. Type of waste collection (Dry/Wet)
6. Waste pickers report
7. Waste pickers route wise collection report
8. Driver-wise/route-wise waste collection report.

One such sample report exported in Excel is shown in Figure 6. It shows the active user report generated from the system.

Using IoT and MIS systems, we aimed to achieve 100% door-to-door rubbish pickup. When we tried and tested this application on two routes in ward 56 in Pune Municipal Corporation with 11 users and 2 waster pickers and 2 drivers, it has given promising results and the system was quite well functioning. It has given 100% results and that has encouraged us to take this system to a wider level.



User_No	UserName	Email	Mobileno	Password	Status	Rfid	apartment	city	pincode	route	street
1	Avinash salunke	avi@yahoo.com	9145766435	12345678	Deactive	09002A2EB0BD	noble manchester	narhe	411041	1 navle hospital	
2	snehal gorad	snehal@hotmail.com	9145785632	123456789	Deactive	09002D690B46	vyankatesh	katraj	411065	2 sinhgad road	
3	komal babar	komal@gmail.com	9456781236	1234567890	Deactive	09002D6A602E	iskon	pune	413256	1 jekkan naka	
4	madhuri patil	madhuri@gmail.com	9456321587	123456789	Deactive	09002D728FE9	pawar house	pune	413702	3 navle bridge	
5	snehal salunkhe	snehal@yahoo.com	9658741236	1234567890	Deactive	09002D910560	shreyash garden	pune	410141	1 datta nagar road	
6	pratima shinde	pratima@gmail.com	9856321475	123456789	Deactive	1D0080A2B082	ashwini heights	pune	411041	2 nathe road	
7	pooja shinde	pooja@gmail.com	9532587412	1234567890	Deactive	1D0080A4D8E1	parthawi imerland	pune	324567	2 swami narayan road	
8	vikas jaiswal	vikas@gmail.com	9876541239	1234567890	Deactive	5500CBF24A26	arihant	narhe	411041	2 navle road	

Figure 6: Generated Report

RESULT ANALYSIS AND DISCUSSION

To understand and analyze our system performance, we extracted data from 1st Feb 2023 to 31st March 2023 from our system for Dry, Wet, Bio and E-Waste collected day-wise. The following table1 shows the waste collected in metric tons for February and March 2023.

Table 1: Month-wise Waste Collection

	dry	wet	bio	e-waste
February	11466	7602	803.7	215.2
March	22354	12577	2793.1	751.18

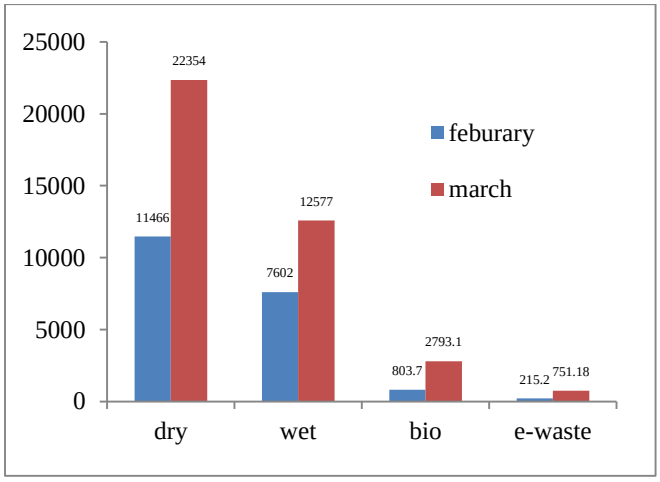


Figure 7: Month Wise Waste Collection

It is observed from the above graph in Figure 7 that the month-wise waste collection had increased from February to March 2023 month in all categories of Waste Management.

On the available dataset, the following is the descriptive analysis report as per Table 2. It is understood from the report that dry waste is almost double that of wet waste. E-Waste is also getting increased month-wise, so need to pay more attention to such kind of waste management shortly.

Table 2: Descriptive Analysis Report

Descriptive Statistics				
	Dry	Wet	Bio	E-Waste
Valid	59	59	59	59
Missing	0	0	0	0
Mean	573.220	342.017	60.963	16.379
Std. Deviation	179.658	78.122	35.647	23.039
Minimum	320.000	230.000	6.100	2.000
Maximum	886.000	498.000	121.600	182.000

CORRELATIONAL PLOT

We have considered "dry', 'wet', 'bio' and 'e-waste' variables from the given data and after processing these variables it is possible to represent the 'correlation' among these variables

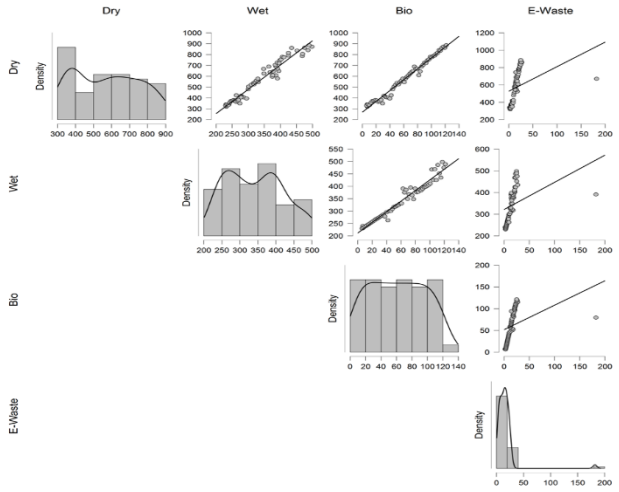


Figure 8: Correlation Plot

From the correlation plot (Figure 8) it is observed that dry-to-wet correlations are highly dense. The density of biowaste is almost similar to 20- 120 metric tons of waste whereas it is not dense when it goes beyond 120+ metric tons. The wet and bio waste is almost in perfect linear relation by observing the graph.

Linear Regression: The extracted dataset from the proposed system consists of dependent, independent variables. Linear regression helps to identify the relationship between these variables. When we applied linear regression analysis on the extracted dataset for two months then we got the following results described in Table 3. For Linear Regression model H0, the results are very poor with 0.000 as R2 whereas for Lasso Regression model H1 the R2 score was quite good as 0.955

Table 3: Linear Regression Analysis

Model Summary - Bio				
Model	R	R^2	Adjusted R^2	RMSE
H_0	0.000	0.000	0.000	35.647
H_1	0.977	0.955	0.954	7.653

Residual plots: These visualize the observed and fitted response values. It plots the 'residual values' on the vertical axis and the 'independent values' on the horizontal axis. When we plot various residual plots (Refer to figure 9) for bio, wet we observed that for bio waste and wet waste, the random scatter of points formed an approximately constant width band around the identity line.

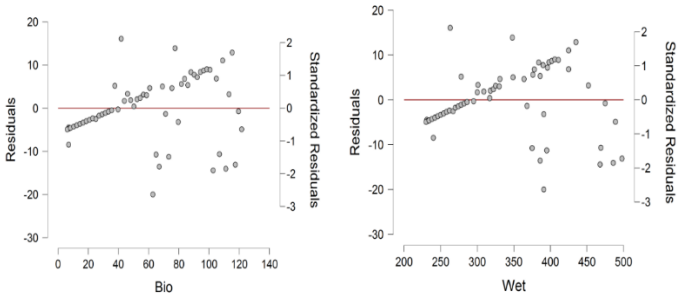


Figure 9: Residual Plot

COMPARATIVE ANALYSIS OF PROPOSED WORK

Many researchers had worked on the Smart Waste management using IoT for cleaner and greener initiative of various Municipal Corporation. In this section, the comparative analysis has been done of the proposed system with existing work. The table 4 summarizes the comparative analysis.

Table 4. Comparative analysis of systems

Methodologies	**Remarks**
IoT,Ultrasonic Sensors, Arduino Uno, Android (S.S. Choudhari 2018)[25]	The system was quite similar compared to what the proposed system, but lacks in separate garbage collection kits for Waste picker van. Centralized Dashboard for admin was also missing hence quantitative analysis can't be done.
IoT, Zigbee,Web Application (A.S. Bhardwaj 2016)[16]	Only the End User Garbage collection was done. No Mobile app for Home user, waste picker van was implemented. No real time monitoring was done.
Microcontroller, level sensor (A. Jain 2017)[26]	Only dustbin level and its status was recorded. No real time mapping through routes and centralized admin control was not implemented.
Microcontroller, Ultrasonic Sensor, RF Transmitter (K. Nirde 2017)[27]	Only local dustbin level was identified and based on that alert will be send. No Real time mapping of data was done
Microcontroller, Ultrasonic sensor, WLAN (S.R.J. Ramson 2021)[19]	User level, region wise dust bin level was identified and waste was collected.

Microcontroller, Sensors, Web Modules (T. Ali 2020)[28]	Central dashboard was implemented. Alert used to send to Waste pickers van. But no real time mapping on routes and data. Android app was missing.
Microcontroller, Routers, Sensors (S. Vishnu 2021)[29]	Home user and public users implementation was done for dust bin level identification. Dashboard was designed for Admin control. But no real time Mapping was done via google map for exact route tracing.
Arduino Uno, GSM, Sensors, Android, Web API Designed System	Dustbin levels were collected via sensors, alert used to send to home uses, waste picker vans, Trucks, Drivers via admin web as well as mobile module. Real time routes were displayed using Google Map. The primary dashboard may be used to retrieve a variety of reports and data. Overall, a comprehensive trash management system.

CONCLUSION

Improper disposal and maintenance of household garbage causes public health and environmental degradation. Hence nowadays many countries are giving a lot of importance to waste management. Indian Government had also launched Swatch Bharat Abhiyan. In this article, we planned and created an IoT-based web and android application to contribute to the clean city programme, with the goal of providing a viable solution for smart trash management. After we tried and tested the prototype model in one ward of the Pune Municipal Corporation, the results were quite encouraging, and we were able to accomplish 100% door-to-door waste. The proposed system also makes awareness of people for waste management and it has the facility to give warnings and alerts to users for non-following of smart waste management. The proposed approach will aid in the resolution of all severe waste concerns and the preservation of the environment.

After analyzing the data (dry, wet, bio and e-waste) it is necessary to reduce the e-waste as it may consist of hazardous material. Though there are many routes identified before collecting the waste, it is suggested to start a campaign from the competent authorities to handle the e-waste.

It is also observed that “plastic” should be banned on an earlier basis. Waste collection may consist of “plastic” and it cannot be decomposable and harms “nature” as well as “animals”. To deal with ‘e-waste’, ‘wet’ and ‘dry (especially plastic)’ there are a few solutions that can be adopted as follow –

1. Educating (awareness campaign) people on the importance of ‘recycling’
2. Recycling
3. Avoiding the use of plastics.
4. Imposing a ban on plastics
5. Reusing the ‘plastics’ and other possible contents from the ‘e-waste’ in the construction of highways.
6. Processing wet waste to create ‘compost’ for agriculture.

Although we achieved a good rate of waste management collection through our system, but still there are certain limitation of our work. Currently we are not catering the other types of waste management which occurs through the Restaurants and Industry. Another limitation is that lot of awareness had been made for the citizens to use this system and there are monthly payment (in terms of Rent/EMI) which need to be paid by every user for this system. Many citizens especially uneducated peoples are refusing to use this system. We need to bring the cost of operation to a very lower (as good as nil) to make this system more and more applicable to everyone from this society.

In our future scope, we wish to take this system to the next level for industrial waste, bio-waste and E-waste management in a smart way for plastic and e-waste-free waste.

The major idea to implement this system was to encourage the Further in future we definitely want to extend this system for other uses like Restaurant owners, Industrial belt so that other kind of waste disposal which is equally important should be also done in same passion with the help of our smart waste management and sooner we can city our city clean and green. House hold users to dump their waste on daily basis. This will lead to equal responsibility to collect the waste from door to door from the waste picker van and will smoothen the system to drop it to final dumping station on a regular basis. This will help to make the waste management system effectively work. We had applied the system with same zest and from the graph shown in figure 7, for which we had collected the data of two months (Feb/March 2023), it is clearly evident that daily waste picking collection had been raised by a considerable amount in month of March 2023 compared to Feb 2023. This show that our contribution to implement this system is going in a correct direction and we had successfully implemented the system.

CONFLICT OF INTEREST

Authors declare that there is no conflict of interest for this work.

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