Development and Implementation of the "EcoRoute" Mobile Application for Smart Waste Collection Practices

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Abstract

Municipal Solid Waste (MSW) management plays a crucial role in maintaining a clean and healthy urban environment. However, in areas such as Ampara in Sri Lanka, waste management systems frequently face challenges such as irregular and poor coordination between households and waste collectors. These result in the use of inappropriate waste management practices by the community, leading to higher levels of pollution. The average daily waste generation rate is 0.64 kg per capita per day in Sri Lanka, but there is a lack of appropriate waste management services in most of the cities. The main objectives of this research were to develop and evaluate the EcoRoute mobile application to enhance household waste collection efficiency and reduce environmental pollution caused by improper disposal practices. The study used a mixed-methods approach, and pre- and post-test surveys were carried out among 185 randomly selected households in three waste collection routes. The sample size was developed using a hybrid cloud model that combined a Flutter-based mobile app with a Firebase database. The system also utilized GPS technology to monitor vehicles in real-time and a feedback system to enhance engagement between residents and officials from the waste management agency. Results showed that there was a notable improvement following the implementation of the EcoRoute system. Knowledge levels regarding waste collection schedules improved among 94.6% of respondents, while missed collection rates decreased by 87.1%. Critically, open burning of waste decreased substantially from 83.3% to 2.7%, and 96.8% of residents reported that odor and pest issues were no longer problematic. Resident satisfaction with communication systems increased from 1% to 81.2%. The "EcoRoute" mobile app proved to be an effective and scalable solution to enhance municipal waste management and establish a cleaner environment.

Keywords: *EcoRoute; Environmental hygiene; Mobile application; Smart Waste Management (SWM); Sri Lanka*

INTRODUCTION

The issue of waste management is a serious problem worldwide, especially due to rapid urbanization, industrialization, and changes in consumer behavior. In 2023, the world produced an estimated 2.3 billion tons of waste, and it is projected to rise to 3.8 billion tons by 2050 (Kaza *et al.*, 2018; WB, 2018; Tennakoon *et al.*, 2025). The issue of poor waste management, such as dumping and burning waste, poses a serious threat to the health of the population and the environment (Knutsson *et al.*, 2021). The issue of waste management is a serious problem in cities worldwide, which are overwhelmed by waste. This aligns with global findings, as a comparative analysis of solid waste management in 20 cities highlighted that even well-established systems face challenges that require context-specific solutions (Wilson *et al.*, 2015). Moreover, the issue of waste management in developing countries such as Sri Lanka is a problem that hinders progress in important areas such as recycling and composting, which are important in reducing the negative effects of poor waste management practices (Bandara *et al.*, 2010; Guerrero *et al.*, 2013). In developing countries, the issue of waste management is a problem that is becoming prominent due to the rapid growth of cities and the population. For instance, people in Sri Lanka produce an estimated 0.64 kg of waste per day, which amounts to 4.8 billion metric tons per year. However, to solve these problems, it is advised to enhance public education, encourage waste reduction and recycling, and adopt alternative approaches like waste-to-energy and composting, besides updating policies to meet zero-waste targets (Lorenz, 2024). The nation is facing serious problems regarding waste management, leading to debates on improved practices and policies. Improper waste management is a serious source of environmental and health hazards, which affects the entire planet. The problem involves different types of waste, such as solid, hazardous, medical, and liquid waste, each having different problems. The environmental impacts are extensive, resulting in air and water pollution, soil contamination, and loss of biodiversity. Improper waste management and open burning result in the release of dangerous pollutants like dioxins and nitrogen oxides, leading to respiratory and cardiovascular diseases among the inhabitants living nearby (Mir *et al.*, 2023). Moreover, the contamination from improperly disposed waste threatens the nearby water bodies and agricultural lands, further increasing health risks and food insecurity, particularly among the vulnerable groups (Yuan and Zoongrana, 2025).

The effects of poor waste management on the health of people are especially felt by marginalized sections of society, such as indigenous populations, who are more vulnerable to infection by diseases due to their proximity to polluted sites. For instance, the improper disposal of biomedical waste has been associated with an outbreak of skin and gastrointestinal diseases (Jakhar *et al.*, 2023). The improper handling of hazardous waste makes the spread of diseases such as hepatitis and HIV easier, which further puts pressure on health care systems in regions where access to medical care is already a problem (Gebrekidan *et al.*, 2024). In addition, socio-economic inequalities in waste management further widen health gaps and create difficulties for affected communities in dealing with health emergencies caused by pollution (Gutberlet and Uddin, 2018). Despite the growing awareness of sustainable waste management practices, there are still many challenges that industrial establishments encounter in their efforts to dispose of waste effectively. As emphasized by Srivastava *et al.* (2022), the lack of effective enforcement of environmental laws and regulations, as well as the lack of economic motivation, are some of the factors that make it difficult for industries to comply with the necessary environmental standards. This has resulted in the continued pollution of soil and groundwater, air, and ecosystems, which ultimately results in rising costs of cleanup and remediation (Srivastava *et al.*, 2022). Moreover, the presence of waste in the community can also affect the quality of life of the community members and can create social inequalities, as marginalized communities have the tendency to dispose of their waste improperly and suffer from the consequences (Hidalgo *et al.*, 2024). Especially in developing nations like Sri Lanka, mobile technology has become increasingly crucial in facilitating the waste management system. Through mobile applications, the waste management system can be optimized by the waste management service providers and the community, and data analytics can be used to improve the utilization of the system. The role of mobile technology in this industry is significant due to its ability to lower costs and promote sustainable practices among the community members, especially in light of the pressing environmental concerns.

Furthermore, the alignment of waste management interventions with the Sustainable Development Goals (SDGs) has gained increasing attention. The EcoRoute system contributes directly to several SDGs, including SDG 11 (Sustainable Cities and Communities) by improving urban waste management services, SDG 12 (Responsible Consumption and Production) by promoting sustainable waste disposal practices and reducing open burning, and SDG 3 (Good Health and Well-being) by minimizing environmental pollution and associated health risks (UN, 2015; Deswal and Deswal, 2025). This alignment with global sustainability frameworks enhances the relevance and impact of the intervention.

Conventional waste management systems may experience inefficiencies in their operations, including a lack of proper communication about waste collection and schedules, causing dissatisfaction among the public and a lack of confidence in waste management services (McAllister, 2015). The introduction of a mobile application that enables real-time monitoring of waste collection trucks and the use of feedback systems by the community presents an effective and novel approach to enhance the efficiency and effectiveness of waste management services (Fheili and Marrouch, 2025). Moreover, shortening the time spent in bins can enable municipalities to enhance air quality and minimize the carbon footprint of waste collection processes (Shadbahr *et al.*, 2022; Couth and Trois, 2010). Additionally, these systems can create a culture of environmentalism among the community, enhance healthy community behavior, and minimize the number of illegal dumping cases (Nguyen *et al.*, 2023; Leknoi *et al.*, 2024). This will enable the optimization of routes, minimize delays, and enhance waste collection schedule adherence. Moreover, the application encourages community participation in waste management services through the submission of missed collection reports and feedback, thus promoting accountability and responsiveness among waste management service providers (Cruz *et al.*, 2024). Overall, integrating a mobile application in waste management not only improves operational efficiency but also promotes public health and fosters community participation, positioning it as an essential tool for modernizing waste collection services and achieving sustainable urban environments (Cruz *et al.*, 2024).

The objectives of this research were to:

- create and assess an intuitive mobile application that enables waste collectors to update their routes, schedules, and real-time locations to improve the effectiveness of household waste collection,
- evaluate the app's performance in reducing environmental pollution and hazardous disposal practices such as open burning and pit dumping, and
- assess the impact of the mobile application on household satisfaction and behavioral change towards sustainable waste management practices.

MATERIALS AND METHODS

Study Area and Population

The study was conducted in an urban area of Ampara, where municipal waste collection services are available but carried out irregularly. The research was focused on two key groups that form the target population:

- Households – Residents who use municipal or private waste collection services; and
- Waste collectors – Personnel responsible for waste collection, including both municipal workers and private sector staff.

Research Design

This study was designed to evaluate how household waste collection efficiency and communication in the Ampara urban area could be improved through the introduction of the EcoRoute app. The research followed a pre- and post-evaluation framework, where data were collected from the same group of participants before and after the introduction of the mobile application.

The approach allowed to compare existing waste collection practices with the changes that occurred following the implementation of the EcoRoute system. By observing real households and waste collectors within their normal working environment, the study ensured that the results reflected genuine behavioral and operational improvements rather than controlled or artificial conditions.

The research process was carried out in three main stages:

I. *Baseline Study (Before Implementation):* A structured survey was conducted among selected households and all waste collectors to identify existing problems such as irregular collection, communication gaps, and environmental issues related to poor waste disposal practices.

II. *System Implementation (Intervention Period):* The EcoRoute mobile application was introduced along selected waste collection routes. Both households and waste collectors used the app over two weeks to provide real-time updates and improve coordination in waste collection activities.

III. *Follow-up Study (After Implementation):* The same survey was administered again after the app had been in use. The responses were compared with the baseline data to identify improvements in household waste disposal behavior, collection efficiency, communication, and satisfaction levels.

Operational Research Models

The study population parameters within the urban area are as follows: total routes: 5 waste collection routes, average households per route: approximately 900 households, total waste collectors: 10 personnel, total trucks: 5 tractors.

Probability Sampling and Sample Size Justification

To ensure the quantitative findings are statistically justifiable and generalizable to the broader population, a probability sampling technique is utilized, supported by a formal sample size calculation.

Probability sampling strategy (Households)

The study uses Stratified Random Sampling to select the household participants, ensuring proportional representation across the geographical segments.

i. *Stratification:* The total population of households is divided into five strata based on the existing waste collection routes.
ii. *Case Area Selection:* Three (3) routes are randomly selected from the five available routes to define the operational case area for the intervention.
iii. *Random Selection:* Within these three selected routes, individual households are selected using a simple random sampling procedure to eliminate selection bias.

Table 1: Corchan's formula variable values.

Variable	Value	Description
Z	1.645	Z-score corresponding to a 90% Confidence Level.
P	0.6	Estimated population proportion (set to maximize variability).
E	0.057	Margin of Error (acceptable error rate).
N	2700	Total estimated household population across the 3 selected routes (900 *3).

Sample Size Calculation

Table 1 above presents the key parameters used in the sample size calculation, including the Z-score, estimated population proportion, margin of error, and total population. These values were applied in Cochran's formula to determine the required sample size for the study. The sample size is determined using Cochran's Formula to ensure a 90% Confidence Level and an acceptable margin of error.

1. *Initial Sample Size*

Cochran's Formula:

$$n = \frac{Z^2 \times p(1-p)}{E^2} \quad (1)$$

where,
Z = 1.645 (90% Confidence)
p = 0.6 (Max. Variability)
E = 0.057 (Margin of Error)

$$\therefore n = [1.645^2 \times 0.6 \times (1-0.6)] / 0.057^2 = 199$$

Applying the rule of thumb: Apply the adjustment if your initial sample size (n) exceeds 5% of the total population. (N)

$$\frac{n}{N} = \frac{199}{2700} = 0.0737\ (7.37\%)$$

2. *Finite Population Correction (Adjusted Sample Size)*

$$n / [1 + \{\frac{n-1}{N}\}] = 199 / [1 + \{\frac{199-1}{2700}\}] \approx 185$$

Per Route: 185/ 3 $\approx$ 62

The final required sample size is 185 households, distributed equally across the three randomly selected routes (185/3 = 62 households per route).

Operational Sample (Census Inclusion)

All 10 waste collectors and all 5 trucks are included in the study. This constitutes a Census inclusion for the operational data, ensuring a comprehensive evaluation of the app's field functionality and impact on all operational staff.

Data Collection Instruments

Data was collected using a single instrument to capture descriptive metrics.

- *Structured Questionnaires (Surveys):* Administered to the 185 sampled households and 10 waste collectors in both the pre- and post-intervention phases. These forms captured metrics related to: Household Behavior: Frequency of timely waste placement, awareness of collection schedules, and reported issues with pests/odors. Collector
- *Efficiency:* Reported communication issues and perceived safety/ease of work.
- *Satisfaction:* User satisfaction (Likert scale) with the collection service and the mobile application.

Data Analysis Methods

The data analysis followed a Mixed-Methods Approach, which analyzes both quantitative and qualitative data to ensure a comprehensive evaluation of the "EcoRoute" application. The study employed descriptive statistical methods to quantify changes to provide rich contextual explanations.

Quantitative Data Analysis

The quantitative data collected from the Structured Questionnaires (Surveys) using the Likert scale (N=185 households, N=10 collectors) were analyzed using Statistical Product and Service Solutions (SPSS) software. Since the analysis focused purely on describing the collected data and the magnitude of change, only Descriptive Statistics was used:

Frequencies and Percentages: These will be calculated to show the distribution of responses (e.g., the percentage of participants who "Agree" or "Strongly Agree") before and after the intervention. The shift in these frequencies will be the primary evidence used to demonstrate a change in household behavior.

System Architecture

The hybrid mobile-based route alert system for efficient household waste collection in Ampara Urban Area employs a modular, cloud-centric architecture that integrates three core components: a Flutter-based mobile application, Firebase cloud backend, and collector/administrator interfaces. This architecture aligns with established patterns observed in mobile waste collection systems, where “most included studies describe a modular system architecture centered on a client-server model” (Magalhaes *et al.*, 2021; Kumar *et al.*, 2022; Keerti *et al.*, 2025).

Hybrid Application Structure

The system utilizes Flutter with Dart programming language to develop a cross-platform hybrid application, enabling deployment across both Android and ios platforms while maintaining a single codebase. The research indicates that “mobile applications were present in 7 studies, with 3 specifically mentioning Android apps” and that systems often use “cross-platform with Flutter” for development (Malolos *et al.*, 2025). The hybrid architecture provides cost-effective development and maintenance while ensuring a consistent user experience across different mobile platforms.

The application uses a three-tier architecture:

- *Presentation Layer:* Flutter-based UI components designed in Figma,
- *Business Logic Layer:* Dart-based application logic with Firebase integration, and
- *Data Layer:* Firestore database supporting real-time synchronization.

Data Flow Architecture

Data flow within the system follows established patterns where “residents submit waste reports or pickup requests via the mobile application” and “this data is transmitted to the cloud backend, where it is processed and routed to collectors and administrators” (Kumar *et al.*, 2022; Wijendra *et al.*, 2022; Asefa *et al.*, 2022).

Block Diagram Description

Fig. 1 illustrates the interaction between three primary components of the EcoRoute system, showing how the mobile application interfaces with the Firestore backend and user interaction layer to facilitate real-time communication and data exchange between residents, waste collectors, and administrators through the cloud-based system.

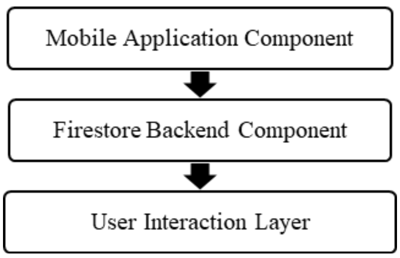

Fig. 1: Block diagram description of App.

- *Mobile Application Component:* Serves as the primary interface for residents and collectors, developed using Flutter with Dart. The application handles user authentication through Firebase Auth, displays route information via Google Maps API integration, and manages real-time notifications.
- *Firestore Backend Component: Functions* as the central data hub, managing user authentication, storing route information, feedback data, and notification logs. Firebase provides “real-time data synchronization and structured storage for user reports, collection schedules, and system logs” (Kitole *et al.*, 2024; Hannan *et al.*, 2020).
- *User Interaction Layer:* Facilitates communication between residents, waste collectors, and system administrators through role-based interfaces. The system

implements "role-based access control models, ensuring secure access for different user types (residents, collectors, administrators)" (Malolos *et al.*, 2025).

Functional Requirements

The functional requirements of the system focus on ensuring secure access, efficient operation, and effective communication between residents and waste collectors. The system implements Firebase Authentication to provide secure login functionality for two user categories, namely residents and collectors. Authentication supports email/password combinations with secure session management and automatic token refresh capabilities. In addition to authentication, the system includes a route alert and update mechanism as a core functionality. Through this feature, collectors can update collection schedules in real time, while residents receive immediate notifications about any changes. Previous research supports the importance of this functionality, noting that scheduling or route optimization and real-time monitoring or status updates were identified as primary features in several studies (Kumar *et al.*, 2022; Wijendra *et al.*, 2022). Furthermore, the system incorporates a feedback and tracking component that enables residents to submit feedback on collection services, report missed collections, and track the status of waste collection. This addresses findings from earlier studies, which indicate that reporting or complaint features were present in only a limited number of systems (Kumar *et al.*, 2022; Wijendra *et al.*, 2022). Overall, these functional requirements directly contribute to improved waste collection efficiency by reducing missed collections, optimizing route planning, and enhancing communication between stakeholders. In the context of urban agriculture in Ampara, efficient waste collection supports environmental hygiene by preventing waste accumulation that could contaminate agricultural areas and water sources.

Non-Functional Requirements

The non-functional requirements of the system focus on ensuring high performance and user-friendly interaction. In terms of performance, the system must support concurrent users with response times under 3 seconds for data retrieval and under 1 second for notification delivery. Firebase's cloud infrastructure provides scalable performance capabilities to meet these requirements. In addition to performance, usability is a key consideration in the system design. The interface must be intuitive for users with varying technical literacy levels, supporting the Sinhala, Tamil and English languages. UI/UX design follows material design principles implemented through Flutter's widget system.

General Features of App

The EcoRoute mobile application is designed to provide an efficient and user-friendly solution for improving waste collection management while promoting environmental sustainability. When users first open the app, they are greeted with a splash screen and onboarding interface that introduces the app's purpose through a clear and engaging message: making waste collection smarter, cleaner, and easier. It highlights key benefits such as real-time updates, live tracking of waste collection vehicles, and helping communities maintain a cleaner environment. After this introduction, users proceed by selecting their role either as a waste collector or a householder, allowing the app to tailor features accordingly. Additionally, users can directly access the live location of waste collection trucks from this stage. Both user types can sign in using their phone number and password, while waste collectors are required to complete a detailed registration process, including personal and professional information such as their name, organization, vehicle number, and identification details to ensure proper authentication and accountability. For waste collectors, the application provides dedicated features to manage and update collection schedules efficiently. Collectors can input and update their daily routes through the "Update Today Schedule" feature or plan ahead using the weekly scheduling option, where routes for each day can be set and saved. They can also view their current daily schedule and quickly navigate to the weekly plan for adjustments. On the other hand, household users benefit from features that enhance communication and convenience. They can view the full weekly collection schedule, access detailed daily collection information, and determine exactly when waste will be collected in their area. A key feature of the app is the live location tracking system, which displays the real-time position of waste collection vehicles on a map. This enables residents to dispose of waste at the right time, reducing unnecessary exposure and contributing to a cleaner environment. Overall, EcoRoute effectively bridges the gap between waste collectors and households by improving coordination, increasing efficiency, and supporting sustainable waste management practices.

RESULTS AND DISCUSSION

The implementation of the EcoRoute mobile alert system has successfully tackled the issues identified at the beginning of the research and has resulted in a significant improvement in all the key performance indicators. The intervention has demonstrated that non-compliant waste services can be transformed into an efficient public service by filling the gaps in communication and operations.

Addressing the Communication Crisis and Ensuring Schedule Certainty

Fig. 2 presents the perception of waste collection schedule knowledge among respondents before and after the

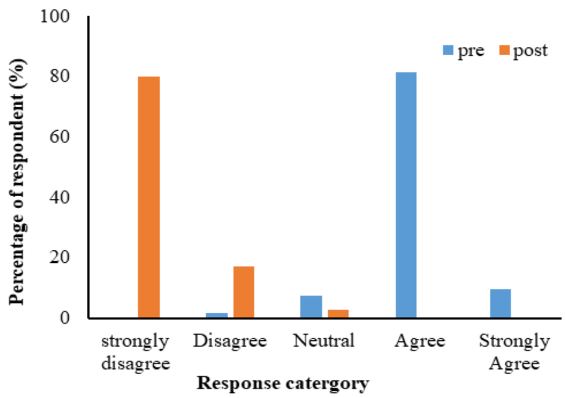

Fig. 2: Perception of waste collection schedule knowledge.

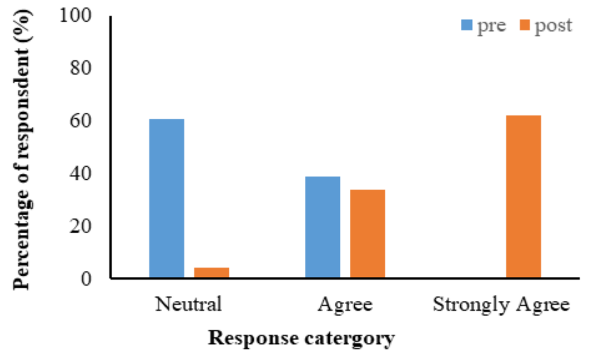

Fig. 3: Ease of remembering the waste collection schedule.

intervention, illustrating the dramatic shift in awareness and certainty.

Before the intervention, there was a significant information gap, with 90.9% of the 185 households surveyed expressing a high level of uncertainty about whether they would be able to receive collection service on a specific day. This persistent communication problem resulted in instability in waste collection and loss of community trust. After the introduction of the mobile app, 80.1% of the surveyed group strongly disagreed with the statement that they did not know the schedule, a complete reversal of the previous situation. Moreover, while 39.2% of the group found it easier to remember fixed schedules, 95.7% of respondents agreed or strongly agreed that the reminders made it easier to manage the schedule through the app.

Fig. 3 illustrates the ease of remembering the waste collection schedule, comparing traditional methods with the mobile application-based reminders.

Enhancements in Service Reliability

Before the study, one of the factors that contributed to dissatisfaction among residents was missed pickups, with 96.7% of the respondents stating that the truck did not arrive at least some of the time on the scheduled day of pickup. The success of the real-time tracking functionality in resolving the issue of missed pickups was evident, as 76.3% of the residents stated that the truck "never" failed to arrive on the scheduled day of pickup after the intervention (Fig. 4).

Effect on Environmental Sanitation and Hazardous Waste Disposal

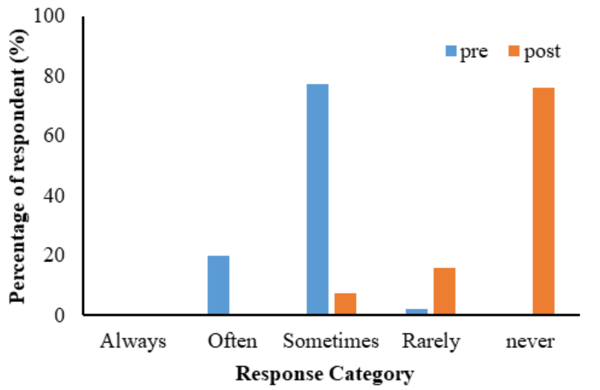

Fig. 4: Frequency of missed collection.

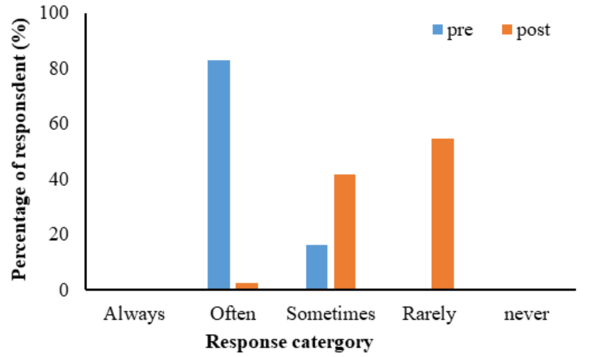

Fig. 5: Open burning of mixed waste.

Fig. 5 presents the significant reduction in open burning practices following the EcoRoute intervention, demonstrating the behavioral change achieved through improved service reliability.

The most significant effect of the intervention was the decrease in environmentally damaging waste disposal. At the start of the intervention, 83.3% of the population confessed to burning mixed waste "often" or "always" as a strategy to cope with the irregular service provision. However, at the end of the intervention, the percentage of the population that regularly practiced open burning was reduced to 2.7%. The system essentially abolished the penalty for self-managing waste through incineration by providing regular and predictable service provision. This had a significant effect on the perception of the population regarding environmental sanitation; 98.4% of the population found odor and pest nuisances to be moderate or extremely severe, whereas 96.8% found them to be none or somewhat severe after the intervention.

Public Satisfaction and Collector Observations

Public satisfaction with the communication system also experienced a universal change, shifting from 99% of the respondents being dissatisfied with the system to 81.2% of the respondents being "very satisfied" with the new system (Fig. 6). The qualitative observations carried out by the 10 waste collectors also supported the results, indicating that the app was helpful for flexible communication with the households. However, a technical limitation was also identified among the older waste collectors who had difficulty coping with smartphone technology. Nevertheless,

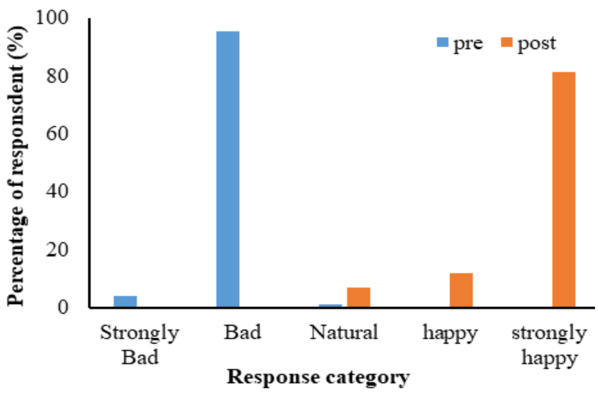

Fig. 6: Satisfaction with the communication system by mobile

the workflow was streamlined, and there was an improvement in the efficiency of municipal waste management operations in Ampara.

The evidence that has been gathered in this research is conclusive in its support of the original hypothesis, proving that the deployment of a mobile application providing real-time updates is indeed an effective means of improving the timeliness and relevance of domestic waste disposal practices. The virtual eradication of the communication crisis and the revolutionary change in disposal practices provide conclusive evidence that the theoretical foundation for the relevance of transparency and real-time information as the primary drivers of service reliability in this field is sound. While the hypothesis has been proven correct, it is clear from this research that there is a crucial "technological adoption barrier" that could be identified to explain any problems with operation: older waste disposal personnel had problems with the smartphone interface. This would seem to suggest that, while the technology is highly effective in operation for the end-user, the internal validity of the operation of the system is partially dependent on the technological awareness of the staff, which could potentially affect the effectiveness of the application unless used in conjunction with staff training.

To make sure that the findings are statistically valid and can be generalized, the study adopted a Stratified Random Sampling approach and Cochran's Formula to make sure that there were no biases in the sampling process and that a representative sample size of 185 households was achieved. Nevertheless, there are some possible threats to internal validity, which include the fact that the intervention phase of the study lasted only two weeks. This may pose a possible threat of the "novelty effect," whereby the respondents may have behaved better because of the novelty of the technology and not necessarily because of a behavior change. Furthermore, the approach adopted in the questionnaires using the Likert scale method may pose a possible threat of imprecision in measurement, which may be attributed to the subjective nature of self-reported satisfaction and nuisance. The margin of error was set at 0.057, which, although acceptable, indicates a possible variability in the quantitative response.

Limitations of the Study

Several limitations should be acknowledged in this study. First, the relatively short intervention period of two weeks may not fully capture long-term behavioral changes or the sustainability of the observed improvements. Longer-term follow-up studies are needed to assess the durability of these changes. Second, the study was conducted in a specific urban area of Ampara, which may limit the generalizability of findings to other regions with different socio-economic and cultural contexts. Third, the self-reported nature of survey data may introduce social desirability bias, where respondents may overreport positive behaviors. Fourth, the study did not include a control group, which would have strengthened the causal attribution of observed changes to the EcoRoute intervention. Fifth, the technical challenges faced by older waste collectors highlight the need for comprehensive training programs to ensure effective adoption of the technology. Finally, the study did not assess the cost-effectiveness of the intervention, which is an important consideration for scaling up the technology in resource-constrained settings.

Practical Implications

The findings of this study have several practical implications for waste management in Sri Lanka and other developing countries. First, the successful implementation of the EcoRoute system demonstrates that mobile technology can effectively address communication gaps in waste management services, providing a cost-effective alternative to expensive hardware solutions. Second, the significant reduction in open burning practices highlights the potential of technology to promote environmentally sustainable behaviors by addressing the root causes of improper disposal. Third, the positive response from households indicates community willingness to adopt digital solutions, suggesting that similar interventions could be scaled across the country. Fourth, the challenges faced by older waste collectors emphasize the importance of capacity building and training programs to ensure inclusive adoption of new technologies. Fifth, the system's ability to provide real-time data can support evidence-based decision-making and policy development for waste management authorities. Finally, the alignment of the intervention with national policies and SDGs provides a framework for integrating such technologies into broader urban development strategies.

The validity of these results is supported by the existing literature, which points out that 70% of the waste in cities in developing countries is left uncollected because of the inefficiencies that EcoRoute was meant to address. The changeover in public satisfaction from general dissatisfaction to near-universal happiness is consistent with the findings of Cruz *et al.* (2024), who found that technology increases public participation. Moreover, the findings of the results regarding the decrease in open burning challenge the conventional wisdom that this practice is a constant cultural tradition, and instead support the findings of Kitole *et al.* (2024), which suggest that improper disposal is often a rational reaction to systemic failure rather than a lack of environmental concern. Additionally, the improvements in collection efficiency and waste disposal practices align with the SDG indicators for sustainable cities and communities (SDG 11) and responsible consumption and production (SDG 12), highlighting the contribution of the EcoRoute system to global sustainability goals.

The relevance of the results is based on the significance of the behavioral change that can be quantified and measured in relation to the disposal of dangerous waste. The study has ensured that the service is reliable, and this has been successful in eliminating the systemic reward of open burning, which was a low-cost option for residents who had irregular services. The study highlights that incorporating digital communication is critical in promoting environmental cleanliness and the achievement of United Nations Sustainable Development Goals (SDGs) 11 and 12 in rapidly growing cities.

CONCLUSION

The "EcoRoute" system is a good example that proves the municipal waste management process can be transformed from an irregular and unreliable process into a stable municipal service using simple and integrated mobile technology. The main result of this research is that the so-called "communication crisis" in urban sanitation is basically an information transparency problem, which can be easily solved by creating feedback cycles between the collectors and the residents. From a professional and practical perspective, this research proves that cloud-focused hybrid apps are highly effective in areas with traditional infrastructure, providing a scalable and cost-effective solution to expensive automated hardware such as smart bins with sensors. From a research perspective, this research provides a critical behavioral finding: dangerous behaviors such as open burning are often reactive to service failure rather than fixed cultural practices; once service delivery is guaranteed through real-time tracking, residents will naturally turn to appropriate disposal. The relevance of these results is based on their potential to directly improve urban environmental and health standards. Looking ahead, the success of this intervention suggests that a country-wide implementation in Sri Lanka is possible. The implications of this intervention suggest that the next generation of this technology should be designed to leverage AI predictive analytics capabilities to predict waste production and further optimize waste collection routes, while also addressing the technology adoption challenges faced by the municipal staff.

Future Research Directions

Several areas warrant further investigation. First, longitudinal studies are needed to assess the long-term sustainability of behavioral changes and the continued effectiveness of the EcoRoute system over extended periods. Second, comparative studies across different urban and rural settings in Sri Lanka would help determine the contextual factors that influence the success of mobile-based waste management interventions. Third, cost-benefit analyses are essential to evaluate the economic viability of scaling up the system, including the financial implications for municipal authorities and households. Fourth, research on integrating artificial intelligence and machine learning algorithms for predictive route optimization and waste generation forecasting would enhance the system's efficiency. Fifth, studies exploring the integration of the EcoRoute system with other smart city initiatives, such as air quality monitoring and traffic management, could create synergistic benefits for urban sustainability. Sixth, research focusing on addressing the digital divide, particularly among older populations and those with limited technology access, is crucial for ensuring inclusive adoption. Finally, policy research examining the institutional and regulatory frameworks needed to support the widespread adoption of smart waste management technologies would be valuable for informing national and local strategies.

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Conflict of Interest

The authors declare that there is not any conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy, have been completely observed by the authors.

Life Science Reporting

No life science threat was practised in this research.

REFERENCES

1) Asefa, E.M., Barasa, K.B. and Mengistu, D.A. (2022) 'Application of geographic information system in solid waste management', in *Solid Waste Management*. IntechOpen. https://doi.org/10.5772/intechopen.103773.
2) Bandara, N., Patrick, J. and Hettiaratchi, J.P.A. (2010) 'Environmental impacts with waste disposal practices in a suburban municipality in Sri Lanka', *International Journal of Environment and Waste Management*, 6(1/2). https://doi.org/10.1504/IJEWM.2010.033987.
3) Couth, R. and Trois, C. (2010) 'Carbon emissions reduction strategies in Africa from improved waste management: A review', *Waste Management*, 30(11), pp. 2336–2346. https://doi.org/10.1016/j.wasman.2010.04.013.
4) Cruz, M., Santos, R. and Delgado, P. (2024) 'Digital tools and public accountability in urban waste systems', *Journal of Sustainable Urban Development*, 18(2), pp. 134–149. https://doi.org/10.1080/14729679.2024.1507831.
5) Deswal, S. and Deswal, P. (2025) 'The Sustainable Development Goals (SDGs): A comprehensive review of progress, implementation, and the path forward', *International Journal of Technology, Health and Sustainability*, 1(2), pp. 133-141. https://ijths.com/wp-content/uploads/IJTHS-010237.pdf
6) Fheili, M.I. and Marrouch, W. (2025) 'Determinants of improper versus proper waste disposal practices by households: Evidence from greater Cairo's urban slums', *Cleaner Waste Systems*, 100410. https://doi.org/10.1016/j.clwas.2025.100410.
7) Guerrero, L.A., Maas, G. and Hogland, W. (2013) 'Solid waste management challenges for cities in developing countries', *Waste Management*, 33(1), pp. 220–232. https://doi.org/10.1016/j.wasman.2012.09.008.
8) Gutberlet, J. and Uddin, S.M.N. (2018) 'Household waste and health risks affecting waste pickers and the environment in low- and middle-income countries', *International Journal of Occupational and Environmental Health*, 23(4), pp. 299–310. https://doi.org/10.1080/10773525.2018.1484996.
9) Hannan, M.A., Begum, R.A., Al-Shetwi, A.Q., Ker, P.J., Al Mamun, M.A., Hussain, A., Basri, H. and Mahlia, T.M.I. (2020) 'Waste collection route optimisation model for linking cost saving and emission reduction to achieve sustainable development goals', *Sustainable Cities and Society*, 62, 102393. https://doi.org/10.1016/j.scs.2020.102393.
10) Hidalgo-Crespo, J.A., Velastegui-Montoya, A., Soto, M., Rivas, J.L.A., Zwolinski, P., Riel, A. and Rivas-García, P. (2024) 'Improving urban waste management: A comprehensive study on household waste generation and spatial patterns in the Grand Guayaquil Metropolitan Area', *Waste Management & Research*, 42(10), pp. 918–931. https://doi.org/10.1177/0734242X241262714.
11) Jakhar, R., Samek, L. and Styszko, K. (2023) 'A comprehensive study of the impact of waste fires on the environment and health', *Sustainability*, 15(19), 14241. https://doi.org/10.3390/su151914241.
12) Kaza, S., Yao, L., Bhada-Tata, P. and Van Woerden, F. (2018) *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1329-0.

13) Keerti, P., Ruchitha, K., Krishna, R.V. and Tabassum, N. (2025) 'IoT-based GPS vehicle tracking and monitoring system', *International Research Journal on Advanced Engineering and Management (IRJAEM)*, 3(5), pp. 2164–2169. https://doi.org/10.47392/IRJAEM.2025.0342.
14) Kitole, F., Mrema, G. and Ndlovu, T. (2024) 'Behavioral responses to systemic waste management failures in developing cities', *Environmental Management Review*, 32(1), pp. 55–72. https://doi.org/10.1016/emr.2024.01.004.
15) Knutsson, S.G., Asplund, T., Höst, G. and Schönborn, K.J. (2021) 'Public perceptions of waste management in Sri Lanka: A focus group study', *Sustainability*, 13(23), 12960. https://doi.org/10.3390/su132312960.
16) Kumar, T. and Raghubanshi, A.S. (2022) 'Waste management practices in the developing nations: Challenges and opportunities'. In: *Waste Management and Resource Recycling in the Developing World*. Elsevier. https://doi.org/10.1016/B978-0-323-90463-6.00017-8
17) Leknoi, U., Painmanakul, P., Chawaloesphonsiya, N., Wimolsakcharoen, W., Samritthinanta, C. and Yiengthaisong, A. (2024) 'Building sustainable community: Insight from successful waste management initiative', *Resources, Conservation & Recycling Advances*, 24, 200238. https://doi.org/10.1016/j.rcradv.2024.200238.
18) Lorenz, C. (2024) *Studies on Optimization Problems with Dynamically Arriving Information*. Doctoral thesis. University of Bologna. https://doi.org/10.48676/unibo/amsdottorato/12266.
19) Magalhaes, E.J.L., Fernandes, M.A., Viana, M.R.P., Martins, M.C.C.E., Lago, E.C., Barbosa, D.A., Corrêa Feitosa, L.G. and Ramos, C.V. (2021) 'Health and work conditions of garbage collectors: A cross-sectional study', *The Open Nursing Journal*, 15, pp. 319–330. https://doi.org/10.2174/1874434602115010319.
20) Malolos, C.F., Maga-ao, M.A.D., Cea, A.P., Magallanes, S.C., Diamante, J.T., Venturillo, R. and Gonzales, B.J. (2025) 'Implementation of Area-Specific Action Plans (ASAP) for community-based MPAs in Cagayancillo, Palawan, Philippines: Funded versus not funded', *The Palawan Scientist*, 17(1), pp. 1–7. https://doi.org/10.69721/TPS.J.2025.17.1.01.
21) McAllister, J. (2015) *Factors Influencing Solid-Waste Management in the Developing World*. Master's report. Utah State University. https://doi.org/10.26076/2c24-5944.
22) Mir, R.A., Mantoo, A.G., Sofi, Z.A. and Bhat, D.A. (2023) 'Types of environmental pollution and its effects on the environment and society', in *Geospatial Analytics for Environmental Pollution Modeling*, pp. 1–31. Springer. https://doi.org/10.1007/978-3-031-45300-7_1.
23) Nguyen, A.T., Nguyen, N., Phung, P. and Nguyễn, Y.-K. (2023) 'Residents' waste management practices in a developing country: A social practice theory analysis', *Environmental Challenges*, 13, 100770. https://doi.org/10.1016/j.envc.2023.100770.
24) Shadbahr, J., Ebadian, M., Gonzales-Calienes, G., Kannangara, M., Ahmadi, L. and Bensebaa, F. (2022) 'Impact of waste management and conversion technologies on cost and carbon footprint: Case studies in rural and urban cities', *Renewable and Sustainable Energy Reviews*, 168, 112872. https://doi.org/10.1016/j.rser.2022.112872.
25) Srivastava, R.R., Rajak, D.K., Ilyas, S. and Kim, H. (2022) 'Challenges, regulations, and case studies on sustainable management of industrial waste', *Minerals*, 13(1), 51. https://doi.org/10.3390/min13010051.
26) Tennakoon, S.M.A.V.S., Udayantha, U.L.I. and Wattegama, W.G.E.J. (2025) 'Waste management research in Sri Lanka: Exploring trends, identifying gaps, and gaining key insights through bibliometric analysis', *Management Dynamics in the Knowledge Economy*, 13(1), pp. 20–37. https://doi.org/10.2478/mdke-2025-0002
27) UN. (2015) *Transforming Our World: The 2030 Agenda for Sustainable Development*. New York: United Nations. https://sdgs.un.org/2030agenda
28) WB (2018). *What a waste 2.0: A global snapshot of solid waste management to 2050*. World Bank. https://doi.org/10.1596/978-1-4648-1329-0
29) Wijendra, D., De Silva, D.I., Gunawardhena, N.M., Wijayarathna, S.M. and Aluthwaththage, J.H. (2022) 'A mobile based garbage collection system', in *2022 3rd International Informatics and Software Engineering Conference (IISEC)*, pp. 1–6. https://doi.org/10.1109/IISEC56263.2022.999826
30) Wilson, D.C., Rodic, L., Scheinberg, A., Velis, C.A. and Alabaster, G. (2015) 'Comparative analysis of solid waste management in 20 cities', *Waste Management & Research*, 33(3), pp. 237–254. https://doi.org/10.1177/0734242X14565236
31) Yuan, Q. and Zoungrana, A. (2025) 'Systematic review of environmental and human health risk assessments in municipal solid waste management', *Discover Sustainability*, 6, 930. https://doi.org/10.1007/s43621-025-01544-8