

SMART WASTE MANAGEMENT SYSTEM

INDIVIDUAL THESIS

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Individual component: Mobile Application for Real-Time Bin Detection, Adaptive
Route Optimization, and Resident-Driven Coordination

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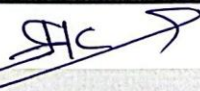
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ABSTRACT

Urban waste collection can be affected by fixed schedules, limited real-time information and weak coordination between residents and collection personnel. This research addresses the need for an integrated mobile workflow that connects IoT-derived critical-bin information with resident–driver coordination. The aim was to develop and evaluate a mobile-based real-time smart waste collection system that supports critical-bin identification, driver map visualisation, resident pickup requests, live vehicle tracking, route support and arrival notification. A design-and-development approach was followed, and the implemented system was evaluated using practical functional, integration and end-to-end testing. Testing covered resident registration and authentication, pickup-request creation, driver-side request visibility, simulated vehicle movement, nearest-truck changes, proximity-based arrival notification, critical smart-bin display, collection interaction, and administrative account recovery. The results demonstrated successful operation of the principal workflows in the controlled test scenarios. The research contribution is not the invention of individual technologies such as IoT sensing, GPS or route assistance, which are established in prior work, but the practical integration of these capabilities into a unified mobile coordination workflow and its evaluation through realistic operational scenarios. The developed mobile component provides a foundation for future field evaluation with residents and professional waste collection drivers.

Keywords: smart waste management, IoT smart bins, mobile application, real-time tracking, waste collection coordination

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
AI	Artificial Intelligence
API	Application Programming Interface
FCM	Firebase Cloud Messaging
GPS	Global Positioning System
IoT	Internet of Things
OSRM	Open Source Routing Machine
OTP	One-Time Password
SWM	Smart Waste Management
UI	User Interface

1 INTRODUCTION

1.1 Overall project context

Urban waste collection is an operational process that depends on timely information about waste locations, collection requests, vehicle movement, and the condition of waste bins. The group project, Smart Waste Management System, was proposed to move waste operations from mainly reactive and schedule-based practices towards more information-driven management. The complete group solution combines IoT-based environmental sensing, smart-bin monitoring, waste-related prediction and a Smart Waste Collection Application.

The individual research reported in this thesis focuses on the mobile application component of the group system. The component provides interfaces and services for residents, waste collection drivers and administrators. Its main functions include real-time critical-bin display, location-based route support, resident pickup requests, live truck tracking, arrival notification, collection confirmation, authentication and account management.

1.2 Individual component context

The individual component is a mobile-based real-time smart waste collection system developed using Flutter. The application supports three main roles: resident, driver and administrator. Residents can submit collection requests and view the movement of a collection vehicle. Drivers can view critical bins, pickup requests and route-related information. Administrators can manage user accounts and recovery requests. The mobile application is connected to Firebase services and a Cloudflare Worker backend. Location services are provided through GPS, while map visualisation uses flutter_map/OpenStreetMap. Route ordering uses a greedy nearest-neighbour heuristic based on Haversine distance, with OSRM used to obtain road-route geometry. The application receives the IoT component's output as a binary critical/normal bin-status event rather than as a continuous fill-percentage measurement.

1.3 Problem statement

Conventional waste collection can depend on fixed schedules and manual coordination. This can create situations in which residents do not have timely information about collection vehicle movement, while drivers may have limited integrated information about urgent waste collection points and resident requests. The lack of direct, real-time coordination can contribute to missed handovers and inefficient collection activities.

The individual problem addressed by this research is therefore the lack of an integrated mobile workflow that connects critical IoT-based bin information, driver-side collection support, resident pickup requests and real-time vehicle coordination. A mobile-based solution is required to provide these functions through a practical collection-support workflow.

1.4 Research gap

Existing research has demonstrated smart-bin monitoring, route assistance, vehicle tracking and resident–collector communication as individual or partially integrated functions. Hanees and Muhammeth [4], for example, demonstrated smart-bin monitoring, driver notification, vehicle location and shortest-route support.

Rathnayake [5] also combined smart-bin information with route assistance and mobile interfaces, while EcoRoute demonstrated mobile communication and real-time vehicle tracking between households and waste collectors in Sri Lanka [3]. Although previous studies have demonstrated individual or partial combinations of these capabilities, limited research has examined their integration into a unified mobile-based real-time coordination workflow involving both residents and waste collection drivers, particularly with practical evaluation of the complete collection interaction. This research therefore focuses on the integration and practical evaluation of such a workflow rather than claiming novelty for any single technology.

1.5 Aim and objectives

Research Aim

To develop and evaluate a mobile-based real-time smart waste collection system that integrates IoT-based bin monitoring and resident–driver coordination to improve the efficiency of urban waste collection.

Research Objectives

1. To integrate IoT-based smart-bin monitoring to identify bins reaching critical waste levels in real time.
2. To develop a mobile-based map interface that enables waste collection drivers to identify and prioritize critical bins.
3. To develop a resident–driver coordination mechanism that enables residents to submit waste pickup requests and drivers to manage those requests.
4. To implement route support for drivers based on their current location and identified waste collection points.
5. To evaluate the usability, functionality, and effectiveness of the developed mobile-based waste collection system.

1.6 Research questions or hypotheses

RQ1. How can IoT-based smart-bin monitoring be integrated into a mobile waste collection system to identify critical bins in real time?

RQ2. How effectively can a mobile map interface support waste collection drivers in identifying and prioritizing critical waste bins?

RQ3. How can a mobile application improve coordination between residents and waste collection drivers?

RQ4. How can location-based route support assist waste collection drivers in managing waste collection points?

RQ5. How usable and effective is the developed mobile-based smart waste collection system for residents and waste collection drivers?

1.7 Scope limitations and assumptions

The research focuses on residents and waste collection drivers, the mobile application, IoT critical-bin integration, real-time coordination, map and location features, route support, resident pickup requests and practical system evaluation. The physical design and manufacturing of IoT hardware, machine-learning waste

composition prediction, physical waste processing, nationwide municipal deployment and truck hardware modification are outside the individual research scope.

The study assumes that the IoT component can provide a critical/normal status to the mobile-system backend and that mobile devices can access GPS and network services. The evaluation is based on controlled practical testing rather than a city-wide deployment.

1.8 Individual contribution

The individual contribution was the enhancement of the user-interface representation and the development and finalisation of the fully functional mobile application for real-time bin detection, adaptive route optimisation and resident-driven coordination. The implementation includes the Flutter mobile application, supporting backend worker functions and database/security integration relevant to the mobile component. The repository evidence records 47 commits touching the `mobile_app` component under the student's development branch.

The contribution includes resident, driver and administrator interfaces; critical-bin map functionality; pickup coordination; live truck tracking; route support; authentication; notifications; account recovery; and supporting backend integration.

1.9 Thesis structure

Chapter 1 introduces the project context, individual problem, research gap, aim, objectives, research questions, scope and contribution. Chapter 2 reviews relevant literature and existing smart waste management approaches. Chapter 3 presents the research design and practical evaluation methodology. Chapter 4 describes the product and solution design. Chapter 5 explains implementation, integration and software testing. Chapter 6 presents the observed results and validation. Chapter 7 discusses the findings in relation to previous research and the research contribution. Chapter 8 discusses commercialization and sustainability. Chapter 9 concludes the research and presents future directions.

2 LITERATURE REVIEW AND RELATED WORK

2.1 Review method and scope

The literature review was focused on research directly related to IoT-enabled smart waste management, smart-bin monitoring, mobile waste collection applications, real-time vehicle tracking, resident–collector communication and route assistance. Six sources were selected to provide a focused evidence base: two systematic reviews, a Sri Lankan mobile application study, a Sri Lankan IoT waste collection system, a smart garbage collection dissertation, and an IoT-based route-optimisation study. Sosunova and Porras [1] systematically reviewed 3,732 retrieved studies and selected 173 primary studies. Zoumpoulis et al. [2] reviewed more than 1,400 publications and selected 79 studies on smart-bin technologies. The remaining studies were selected because they closely match the technologies and operational workflows of the present research.

2.2 Domain and theoretical foundations

Smart waste management applies sensing, communication, information systems, geographical technologies and decision support to waste collection. Sosunova and Porras [1] identify smart-bin data, garbage-truck information, route planning and optimisation, and information support for drivers, dispatchers and citizens as important elements of smart waste management.

Smart bins commonly provide fill-level monitoring and IoT connectivity.

Zoumpoulis et al. [2] identify these capabilities as a widely accepted basis for smart bins, while also noting challenges in automation and standardisation. In the present research, the mobile application consumes the IoT component's critical/normal status and turns the critical state into an actionable driver-side map indication.

Location-aware collection support is another important concept. GPS information can provide vehicle visibility and can be used to support proximity detection and route assistance. Mobile interfaces then act as the operational layer through which residents and drivers interact with the information.

2.3 Related research

Hanees and Muhammeth [4] proposed an IoT-based waste collection monitoring system in Sri Lanka using ultrasonic sensors, Wi-Fi and mobile applications. Filled-bin information was sent to a central system, which could notify a nearby driver. The driver application displayed bin and vehicle locations and provided shortest-path support, while citizens could submit complaints.

Rathnayake [5] developed a smart garbage collection system with route assistance, combining smart-bin information, a central dashboard and mobile interfaces for drivers, collectors and residential customers.

Mehta et al. [6] presented Trash Tech, an IoT-based system combining real-time fill-level and gas monitoring with route optimisation. Their experimental evaluation in Mumbai reported operational benefits, demonstrating the potential of real-time sensing for collection planning.

Udawaththaa et al. [3] developed and evaluated the EcoRoute mobile application in Sri Lanka. The study involved 185 households and 10 waste collectors and used GPS-based vehicle monitoring, collection information and resident–collector feedback. Its results demonstrate the practical value of mobile communication and real-time vehicle tracking.

Together, these studies show that the individual technologies required by the present research have already been investigated. The opportunity for the present study is therefore the integration and practical evaluation of the complete resident–driver coordination workflow with critical IoT-bin information.

2.4 Existing systems products and techniques

Existing systems use different combinations of sensors, cloud services, mobile applications, maps and optimisation techniques. Hanees and Muhammeth [4] used ultrasonic sensing and an Android application. EcoRoute [3] used Flutter, Firebase and GPS. The present application also uses Flutter and Firebase, but integrates a Cloudflare Worker backend, real-time Firestore streams, GPS-based tracking, OpenStreetMap map visualisation and OSRM road geometry.

The route service in the present application uses a greedy nearest-neighbour heuristic based on Haversine distance for ordering collection points. OSRM is then used for

road-route geometry. This provides practical route support but is not claimed to be a globally optimal routing algorithm. The implementation also uses a rerouting threshold and a fixed arrival radius to support real-time interaction.

2.5 Gap synthesis and conceptual framework

The reviewed literature shows that smart-bin monitoring, route support, vehicle tracking and resident communication are established capabilities. However, they are implemented with different emphases across studies. The present research addresses an integration-oriented gap by connecting critical-bin information and driver support with resident pickup requests, live vehicle tracking, arrival notification and collection confirmation.

The conceptual workflow is:

IoT smart bin → critical status → backend/real-time data → driver map → collection prioritisation

and, in parallel:

Resident → pickup request → driver location → live tracking → proximity detection → arrival notification → collection confirmation.

The two workflows are connected through the mobile application. The conceptual framework therefore treats the mobile application as the operational coordination layer between IoT information, drivers and residents.

3 RESEARCH METHODOLOGY

3.1 Research design

The research follows a design-and-development approach combined with practical system evaluation. The process consisted of problem identification, literature review, requirement identification, system design, implementation, integration, functional testing, end-to-end testing and evaluation.

The evaluation was based primarily on practical functional and integration testing. It was not designed as a large-scale participant survey. This distinction is important because the evidence available for this thesis demonstrates system behaviour through controlled scenarios rather than statistically generalisable user-study results.

3.2 Data participants or study materials

The principal study materials were the developed mobile application, backend services, Firebase/Firestore data services, GPS/location services, map services and an IoT smart-bin device. Practical tests used a laptop as a resident-side device and a smartphone as a driver-side device. A motorcycle was used to physically move the driver device to simulate collection-vehicle movement.

No formal demographic participant sample or questionnaire dataset was collected for the individual evaluation. Therefore, the thesis does not claim statistically representative user validation.

3.3 Experimental or study procedure

Testing covered registration and OTP verification, password recovery, resident pickup requests, driver-side request visualisation, driver movement, resident-side live tracking, nearest-truck changes, arrival notification, critical-bin detection and display, collection interaction, user deactivation, recovery requests and account reactivation.

The resident-driver workflow was tested from request creation through vehicle movement and arrival. The IoT workflow was tested by causing the smart bin to enter a critical state and observing whether the critical indication appeared on the driver map. Two driver devices were used in a nearest-truck scenario to observe whether the displayed nearest vehicle changed when their relative positions changed.

3.4 Measures and evaluation metrics

The main evaluation measures were functional correctness, successful completion of defined test cases, real-time location update behaviour, critical-bin display behaviour, pickup-request propagation, arrival-notification behaviour, nearest-truck update behaviour, route-support operation and authentication/account-management behaviour.

The study does not report GPS accuracy, notification latency, route-efficiency improvement or usability scores because these measurements were not systematically instrumented during the existing testing. These are identified as future evaluation opportunities rather than invented results.

3.5 Data analysis

Test outcomes were analysed descriptively by comparing the expected behaviour with the observed behaviour. Each defined test case was recorded as Pass when the observed behaviour matched the expected behaviour. Screenshots and recorded videos provide supporting evidence.

A functional success rate may be calculated as the number of passed test cases divided by the total number of executed test cases, multiplied by 100. Because the final evidence package and exact test-case count must be reconciled before submission, no unsupported numerical success rate is asserted in this draft.

3.6 Ethics privacy security and responsible AI

The evaluation involved authentication and location-related system data. Such information should be used only for system testing and research purposes.

Screenshots included in the final submission should mask personal identifiers, phone numbers, email addresses, tokens and other sensitive information where necessary.

The thesis does not present fabricated survey data or fabricated performance measurements. Any generative-AI assistance used during drafting must be disclosed in accordance with the SLIIT module policy, and the candidate remains responsible for checking the accuracy, originality, citations, implementation claims and final conclusions.

3.7 Reproducibility and research artefacts

The evaluation can be reproduced using the documented workflows: resident login and pickup request, driver login and movement, two-driver nearest-truck simulation, critical IoT-bin event, and administrator account-management scenarios. The final thesis should include selected screenshots and, where permitted, references to the recorded testing videos as supporting evidence.

The technical implementation is based on Flutter/Dart, Firebase services, Cloudflare Workers, Firestore, geolocator, flutter_map/OpenStreetMap and OSRM. The route-ordering method is a greedy nearest-neighbour heuristic, while road geometry is obtained from OSRM.

4 PRODUCT AND SOLUTION DESIGN

4.1 Requirements

The mobile component was designed around the requirements of three roles.

Resident requirements include account registration and authentication, profile access, pickup-request creation, viewing pickup status, live truck tracking, notifications, reporting bin problems and viewing collection announcements.

Driver requirements include access to pickup requests, a critical-bin priority map, route support, navigation-related information, pickup status handling, reports and live location sharing.

Administrator requirements include user management, driver management, account deactivation, recovery-request handling and account reactivation.

The design also addresses non-functional requirements identified by the group project: performance, security, usability, reliability, privacy, compatibility and maintainability.

Table 4.1 Main functional requirements

Requirement area	Main requirements
Resident	Registration/OTP, pickup requests, live truck tracking, notifications, reports, announcements
Driver	Critical-bin map, pickup requests, route support, navigation information, status handling
Administrator	User management, driver management, deactivation, recovery and reactivation
Non-functional	Performance, security, usability, reliability, privacy, compatibility and maintainability

4.2 Component architecture within the complete solution

The mobile component operates as one part of the wider Smart Waste Management System. The IoT component provides critical/normal bin-status events. The mobile application consumes the relevant status through backend and database services.

The main architecture is:

ESP32 smart bin

- HTTP /bin-status
- Cloudflare Worker
- Firestore
- Flutter application
- Driver critical-bin map.

For resident-driver coordination:

Resident Flutter app

- Firestore/backend
- pickup request
- Driver Flutter app.

For location and route support:

Driver device

- geolocator/GPS
- on-device nearest-neighbour ordering
- OSRM road geometry
- flutter_map/OpenStreetMap.

The web dashboard and machine-learning backend belong to other group components and are not directly connected to the mobile application.

MOBILE-BASED SMART WASTE COLLECTION SYSTEM — ARCHITECTURE

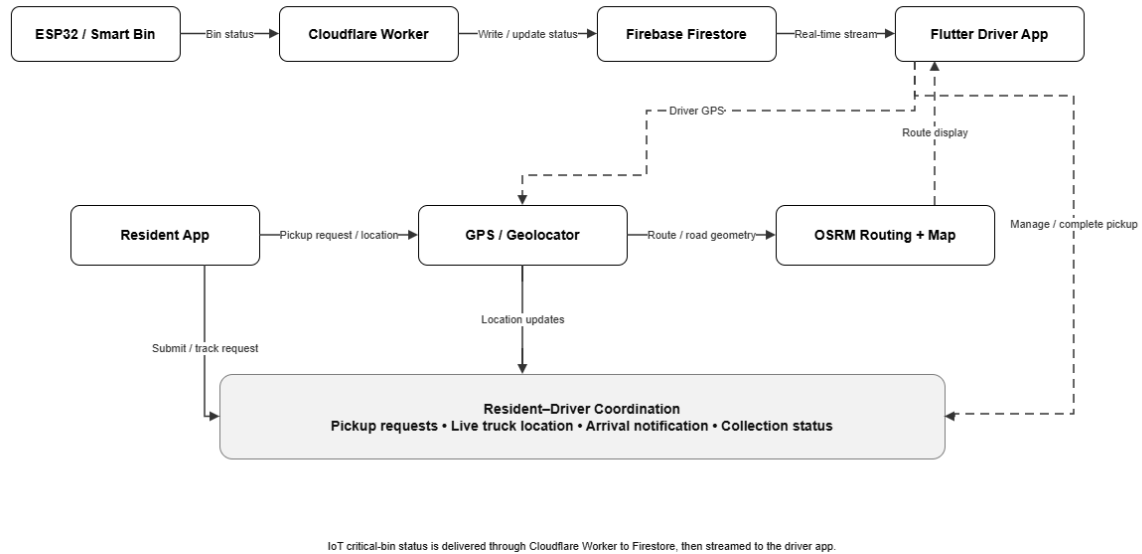


Figure 4.1 System architecture of the mobile component.

4.3 Design alternatives and decisions

A mobile-first interface was selected because residents and drivers require access while moving through collection activities. Flutter was selected to provide a common application framework. Firebase was used for authentication, Firestore data storage and real-time streams. A backend worker was used for server-side functions such as OTP-related processing and protected data operations.

For mapping, OpenStreetMap-based visualisation was used with `flutter_map`. OSRM was selected for road-route geometry. The route ordering uses a greedy nearest-neighbour heuristic because it is simple enough to execute on the device and provides practical route ordering without requiring a full optimisation solver.

4.4 Detailed design

The application is organised around role-based routing and services. Authentication state determines whether a user can access the resident, driver or administrator

functions.

The pickup workflow stores a request with resident identity, coordinates, creation time, expiration time and status. Driver location records contain latitude, longitude, operating mode and update information. The resident application uses driver-location data to display relevant trucks and update the nearest vehicle.

Critical-bin information is represented as an event-driven critical/normal state. A critical event results in a visible driver-side map marker and priority information. The application does not treat the mobile component as the source of the physical sensor measurement.

Route support orders collection points using a greedy nearest-neighbour approach and requests road geometry from OSRM. A rerouting threshold is used to respond to movement away from the active route. Arrival detection uses a configured proximity radius.

4.5 Standards and professional practice

The implementation follows role-based access, authentication, protected database rules and separation of backend responsibilities. The application uses Material 3 interface conventions, loading/error/empty states and map legends to improve clarity.

OpenStreetMap is used for map data and OSRM for road-route geometry. Firebase Authentication and Firestore security rules are used to protect access to user and operational data. The final deployed system should also respect the terms and attribution requirements of the external services used.

5 IMPLEMENTATION INTEGRATION AND TESTING

5.1 Development environment and technology stack

The mobile application was developed using Flutter and Dart. The main technologies used in the component include Firebase Authentication, Cloud Firestore, Firebase Cloud Messaging, Firebase Crashlytics, Cloudflare Workers using TypeScript, EmailJS, flutter_map, OpenStreetMap, OSRM, geolocator, Provider and GoRouter.

Flutter provides the application UI and application logic. Provider supports application state. GoRouter manages navigation and role-based route access. Firebase Authentication provides account authentication, while Firestore provides application data and real-time streams. Cloudflare Workers provide backend functions. Geolocator provides GPS information. Flutter_map and OpenStreetMap provide map visualisation, and OSRM provides road-route geometry.

5.2 Component implementation

The application contains approximately 30 routes/screens covering authentication, resident functions, driver functions and administrator functions. Resident functionality includes pickup requests, truck tracking, reports, notifications and announcements. Driver functionality includes bin priority, pickup requests, route support, missed requests and critical reports. Administrator functionality includes user management and account recovery.

The pickup service implements a 1–3 hour pickup window. Requests can expire automatically, and arrival can be detected when the driver enters the configured proximity range. Collection confirmation is represented through the request-status workflow.

The route service uses an $O(n^2)$ greedy nearest-neighbour ordering based on Haversine distance. OSRM is used after ordering to provide road geometry. The system can trigger rerouting when the driver moves beyond the configured route-deviation threshold.

5.3 Integration with the other components

The mobile application integrates with the IoT component through the critical/normal bin-status event. It also integrates with the backend and Firestore for pickup requests, driver locations, reports, notifications and user-management data.

The practical integration test confirmed the important IoT workflow: a critical bin condition resulted in a red critical-bin indication on the driver's map. The resident-driver workflow was also tested end-to-end, including request creation, driver visibility, live movement, nearest-truck changes and arrival notification.

5.4 Verification and software testing

Verification used manual functional, integration and end-to-end tests. The principal test cases are listed in Table 5.1.

The testing covered registration/OTP, password reset, resident pickup requests, driver request visibility, driver movement, live tracking, nearest-truck updates, arrival notification, critical-bin display, critical-bin selection/viewing, administrative deactivation, recovery and reactivation.

The repository itself contains limited automated testing, so the evaluation reported in this thesis is explicitly described as practical manual testing rather than automated software-test coverage.

5.5 Deployment and operation

The application operates using network-connected mobile devices with location services enabled. Residents and drivers authenticate according to their assigned roles. Driver location information is published while the driver is operating in the relevant mode, and residents can view applicable pickup-mode vehicles.

The system is intended as a prototype/individual research component rather than a claim of full municipal deployment. Large-scale deployment would require

additional operational testing, infrastructure planning, fleet integration, privacy review and performance monitoring.

Table 5.1 Main test cases

Test ID	Test scenario	Expected result	Observed result	Status
TS-01	Resident registration and OTP	Registration completes	Registration/OTP worked	Pass
TS-02	Password recovery	Reset process works	Password reset worked	Pass
TS-03	Resident creates pickup request	Request appears to driver	Request appeared on driver map	Pass
TS-04	Driver starts trip	Location becomes available	Location updated	Pass
TS-05	Real-time driver tracking	Resident sees movement	Movement displayed	Pass
TS-06	Driver approaches pickup	Arrival notification	“Truck is here” appeared	Pass
TS-07	Nearest truck changes	Nearest truck updates	Displayed truck changed	Pass
TS-08	Critical IoT bin	Critical bin appears	Red critical marker appeared	Pass
TS-09	Driver views critical bin	Collection point identifiable	Critical bin visible	Pass
TS-10	Admin deactivates user	Login restricted	Login restricted	Pass
TS-11	Account recovery	Account can be restored	Account re-enabled	Pass
TS-12	Re-enabled login	User can login	Login successful	Pass

6 RESULTS AND VALIDATION

6.1 Research results

The practical evaluation demonstrated successful execution of the principal workflows defined for the mobile component. A resident was able to create a pickup request and the request became visible to the driver on the map. The driver device could be physically moved to simulate a collection vehicle, and the resident application reflected the movement.

When the driver approached the pickup point, the configured proximity condition was reached and the resident received the “Truck is here” notification. A two-truck scenario also demonstrated that the displayed nearest vehicle could change as the relative locations of the two drivers changed.

The IoT integration test demonstrated that a critical smart-bin state could appear on the driver's map as a red critical-bin indicator. Authentication and administrative recovery workflows were also successfully exercised.

6.2 Product and technical results

The resulting mobile component provides resident, driver and administrator functionality within one application. It integrates real-time Firestore streams, GPS tracking, map visualisation, route support, critical-bin information, pickup requests, notifications and account management.

The route implementation provides practical route ordering and road geometry, but it should not be interpreted as an optimal vehicle-routing solution. The greedy nearest-neighbour approach is computationally simple and suitable for prototype route support, while future work could incorporate traffic, waste priority, vehicle capacity and global optimisation.

6.3 User or stakeholder validation

A formal participant-based usability study was not conducted as part of the available individual evaluation evidence. Therefore, this thesis does not report a SUS score,

satisfaction percentage, demographic analysis or statistically generalisable user-validation result.

Instead, the system was validated through realistic stakeholder-role scenarios using a resident-side device and driver-side device. These scenarios provide practical evidence that the principal resident and driver workflows can operate together.

6.4 Integration results

The most important integration results were observed in two workflows. First, the IoT-to-driver workflow successfully propagated a critical-bin condition to the driver map. Second, the resident-to-driver workflow successfully propagated a pickup request, driver movement and proximity event to the resident interface.

The two-driver scenario provided additional evidence that the application responds dynamically to changes in vehicle location rather than treating the nearest vehicle as a fixed value.

6.5 Summary of findings

The practical testing supports the following findings:

- The resident pickup-request workflow operated successfully.
- Driver-side pickup information was visible on the map.
- Driver movement could be observed from the resident side.
- The nearest-truck display could change as vehicle positions changed.
- The proximity condition generated the expected arrival notification.
- A critical IoT-bin event was represented on the driver map.
- Registration/OTP and password-recovery workflows were exercised successfully.
- Administrative deactivation, recovery and reactivation workflows operated as expected.

These findings demonstrate functional feasibility. They do not establish city-wide

efficiency gains, statistically measured usability, route-efficiency improvement or large-scale operational effectiveness.

Table 6.1 Summary of practical test outcomes

Area	Observed outcome	Evidence to insert
Pickup request	Resident request appeared on driver map	Figure A.1–A.2
Live tracking	Driver movement visible to resident	Figure A.3–A.4 / video
Arrival	Proximity condition generated “Truck is here”	Figure A.5
Nearest truck	Displayed nearest truck changed with movement	Figure A.6 / video
IoT critical bin	Critical bin appeared in red on driver map	Figure A.7–A.8
Authentication	OTP and password recovery workflows operated	Figure A.13–A.14
Admin recovery	Deactivation, recovery and reactivation operated	Figure A.10–A.12

7 DISCUSSION

7.1 Interpretation of findings

The results indicate that the mobile application can act as a practical coordination layer between residents, drivers and IoT-derived collection information. The resident pickup request creates an operational demand, while the driver-side map provides the driver with the location required to respond. Live GPS updates and proximity detection then connect vehicle movement with resident-facing feedback.

The critical-bin workflow similarly converts an IoT event into actionable information for the driver. This supports the principle identified by Sosunova and Porras [1] that smart waste management can combine sensor data, collection-vehicle information, route planning and stakeholder decision support.

7.2 Comparison with literature baselines and existing solutions

The results are consistent with earlier work demonstrating that smart-bin information can be connected to driver support. Hanees and Muhammeth [4] already demonstrated filled-bin alerts, driver location and shortest-path assistance. Rathnayake [5] also combined smart-bin information with route assistance and mobile interfaces.

The resident-facing coordination aspect is closely related to EcoRoute [3], which demonstrated live vehicle tracking and communication between households and collectors in Sri Lanka. Therefore, the present work should not be interpreted as introducing each of these capabilities independently.

The contribution is instead the integration of critical-bin awareness, driver-side collection support and resident pickup coordination into one mobile operational workflow, together with practical end-to-end testing of the interaction between those functions.

Table 7.1 Comparison with Reviewed Literature

Study	IoT Smart Bin	Driver Support	Live Tracking	Resident Interaction	Route Support
Hanees and Muhammeth (2018)	Yes	Yes	Yes	Complaints	Yes
Sosunova and Porras (2022)	Yes	Yes	Reviewed	Reviewed	Yes
Zoumpoulis et al. (2024)	Yes	Partial	Partial	Limited	Yes
Rathnayake (2024)	Yes	Yes	Yes	Yes	Yes
Mehta et al. (2025)	Yes	Yes	Yes	Limited	Yes
Udawaththaa et al. (2026) – EcoRoute	Not a main focus	Yes	Yes	Yes	Schedule/route support
Proposed System	Critical-bin status	Yes	Yes	Yes	Yes

7.3 Research contribution

The research contribution is an evidence-based integration of established smart waste management capabilities into a unified mobile coordination workflow. The study provides a practical demonstration of how an IoT-derived critical-bin event can be connected to a driver map while resident pickup requests and live truck tracking operate in parallel.

The research also contributes a clearly defined evaluation approach for the developed prototype, based on functional, integration and end-to-end scenarios.

7.4 Product contribution

The product contribution is the completed mobile application component for real-time bin detection, adaptive route support and resident-driven coordination. The implementation provides role-based interfaces, real-time data streams, location

services, map visualisation, pickup management, notifications and administrative controls.

The application is designed as a component within the wider group Smart Waste Management System and therefore does not claim ownership of the other group's machine-learning prediction or physical IoT-hardware development.

7.5 Limitations and threats to validity

The principal limitations are the controlled nature of the practical tests, the absence of a large participant sample, the use of a motorcycle and smartphone to simulate collection-vehicle movement, and the absence of systematically measured route-efficiency, GPS-accuracy and latency baselines.

The route heuristic is not globally optimal and does not account for traffic, vehicle capacity or load balancing. The mobile component receives a binary critical/normal bin state rather than continuous fill percentage, waste type or ML prediction. These limitations constrain the extent to which the findings can be generalised to municipal-scale operations.

7.6 Implications

The results suggest that mobile coordination can complement IoT-based waste monitoring by turning sensor events into operational information for drivers and by giving residents visibility of collection progress. For municipal deployment, additional field studies would be required to measure travel time, fuel consumption, collection efficiency, user satisfaction, notification latency and reliability under real network conditions.

The practical integration approach may be extended by adding richer IoT measurements, more advanced route optimisation, fleet assignment and structured usability evaluation.

8 COMMERCIALISATION AND SUSTAINABILITY

8.1 Value proposition and target users

The proposed solution provides a mobile coordination layer for waste collection stakeholders. Residents gain a mechanism for requesting collection and viewing relevant vehicle movement. Drivers gain visibility of critical bins and pickup requests together with location and route support. Municipal or waste-management administrators gain user-management and operational information functions.

The primary target users are municipal waste collection organisations, private waste collection operators, waste collection drivers and residents in urban service areas.

8.2 Market and competitive position

Existing research demonstrates that smart-bin monitoring, route assistance and resident communication are established solution areas. The competitive position of the proposed component therefore depends on integration, practical usability and adaptability rather than a claim that its individual technologies are unique.

A future product could differentiate itself through configurable municipal workflows, richer IoT sensing, fleet assignment, analytics, service-level monitoring and integration with existing council systems.

8.3 Business or sustainability model

A potential deployment model is a service-based arrangement in which a municipal council or private waste operator subscribes to the platform. Costs would arise from application maintenance, cloud services, mapping/route services, notification infrastructure, IoT devices and operational support.

The system may contribute to sustainability by improving the timing and prioritisation of collection and reducing unnecessary travel. However, actual fuel or carbon savings were not measured in the present study and should be validated through future field trials.

8.4 Scalability intellectual property and compliance

The mobile architecture can be scaled by adding users, vehicles, wards and collection points through cloud-backed services. A production deployment would require load

testing, stronger observability, service-level monitoring, secure secret management, data-retention policies and formal privacy/compliance review.

The software, interface design and implementation artefacts should be managed according to the intellectual-property and academic rules applicable to the group project and SLIIT. External services such as map tiles and routing APIs must be used according to their respective terms and attribution requirements.

8.5 Contribution to the Sustainable Development Goals

The system has potential relevance to Sustainable Development Goal 11 (Sustainable Cities and Communities) through improved urban-service coordination and to SDG 12 (Responsible Consumption and Production) through more efficient waste-management processes. These are potential contributions rather than measured SDG impacts. Quantitative environmental benefits require future field evaluation.

9 CONCLUSION AND FUTURE DIRECTIONS

9.1 Conclusion

This research developed and evaluated a mobile-based real-time smart waste collection system that integrates IoT-derived critical-bin information with resident–driver coordination. The system provides role-based mobile interfaces, critical-bin mapping, pickup requests, live vehicle tracking, arrival notification, route support and account-management functions.

Practical functional, integration and end-to-end testing demonstrated that the principal workflows could operate together in controlled scenarios. The findings support the feasibility of using a mobile application as a coordination layer between IoT information, residents and waste collection drivers.

9.2 Achievement of objectives

Objective 1 was addressed by integrating the IoT component's critical/normal bin status into the driver-side mobile application.

Objective 2 was addressed through the driver map and critical-bin visualisation, allowing drivers to identify collection points requiring attention.

Objective 3 was addressed through resident pickup requests and driver-side request management.

Objective 4 was addressed through GPS-based location services and route support using nearest-neighbour ordering and OSRM road geometry.

Objective 5 was addressed through practical functional, integration and end-to-end testing. The evaluation demonstrates functional feasibility, while formal usability and large-scale effectiveness remain subjects for future work.

9.3 Individual research and product contributions

The individual contribution was the development and finalisation of the mobile application component for real-time bin detection, adaptive route support and resident-driven coordination. The work included user-interface enhancement, resident and driver workflows, administrator functions, authentication, pickup coordination, live tracking, map and route services, notifications and supporting backend integration.

The research contribution is the practical investigation of how these established capabilities can be integrated into a single mobile coordination workflow and evaluated through realistic operational scenarios.

9.4 Future directions

Future work should include a formal usability study with residents and professional waste collection drivers, measurement of notification and IoT-event latency, GPS-arrival accuracy analysis, route-efficiency comparison against baseline routes, field trials with real collection vehicles, and longer-term reliability evaluation.

The route service could be extended with traffic conditions, vehicle capacity, waste priority, load balancing and more advanced optimisation. The IoT integration could expose richer sensor information such as fill percentage and environmental measurements. Further work could also integrate the mobile application with the group's prediction and municipal-dashboard components to create a more complete operational platform.

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GLOSSARY

Term	Definition
Smart waste management	Use of digital, sensing and information technologies to support waste collection and management.
Smart bin	A waste container equipped with sensing/connectivity capabilities such as fill-level monitoring.
Critical bin	A bin reported by the IoT component as requiring attention according to the implemented critical/normal state.
Pickup request	A resident-generated request indicating a location and collection time window.
Nearest-neighbour routing	A heuristic that repeatedly selects the nearest unvisited point to build a route order.
Real-time tracking	Updating and displaying vehicle location as the driver device changes position.
Proximity detection	Determining whether the driver has entered a configured distance from a pickup point.
End-to-end testing	Testing a complete workflow across multiple connected system components.

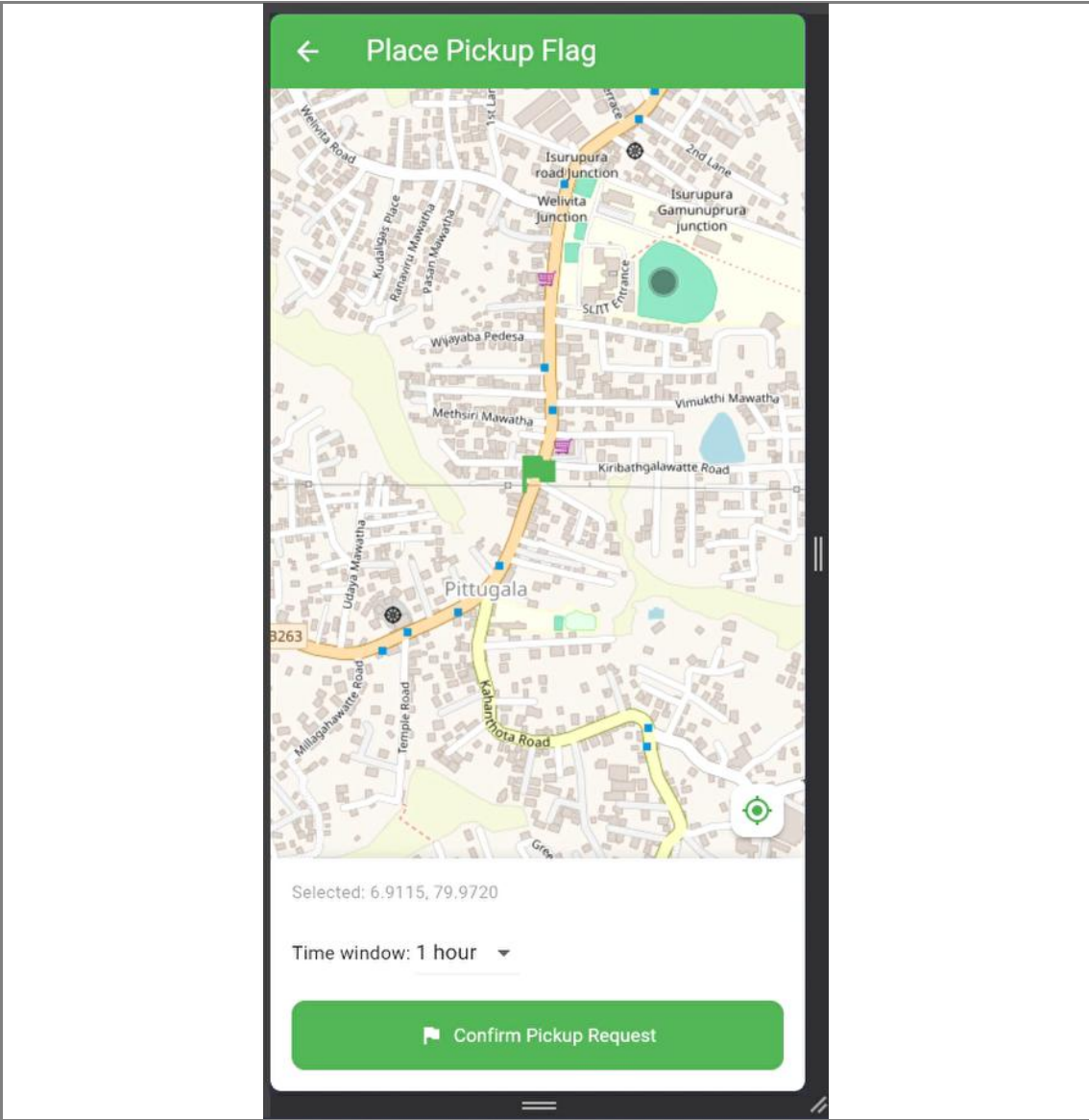
APPENDICES

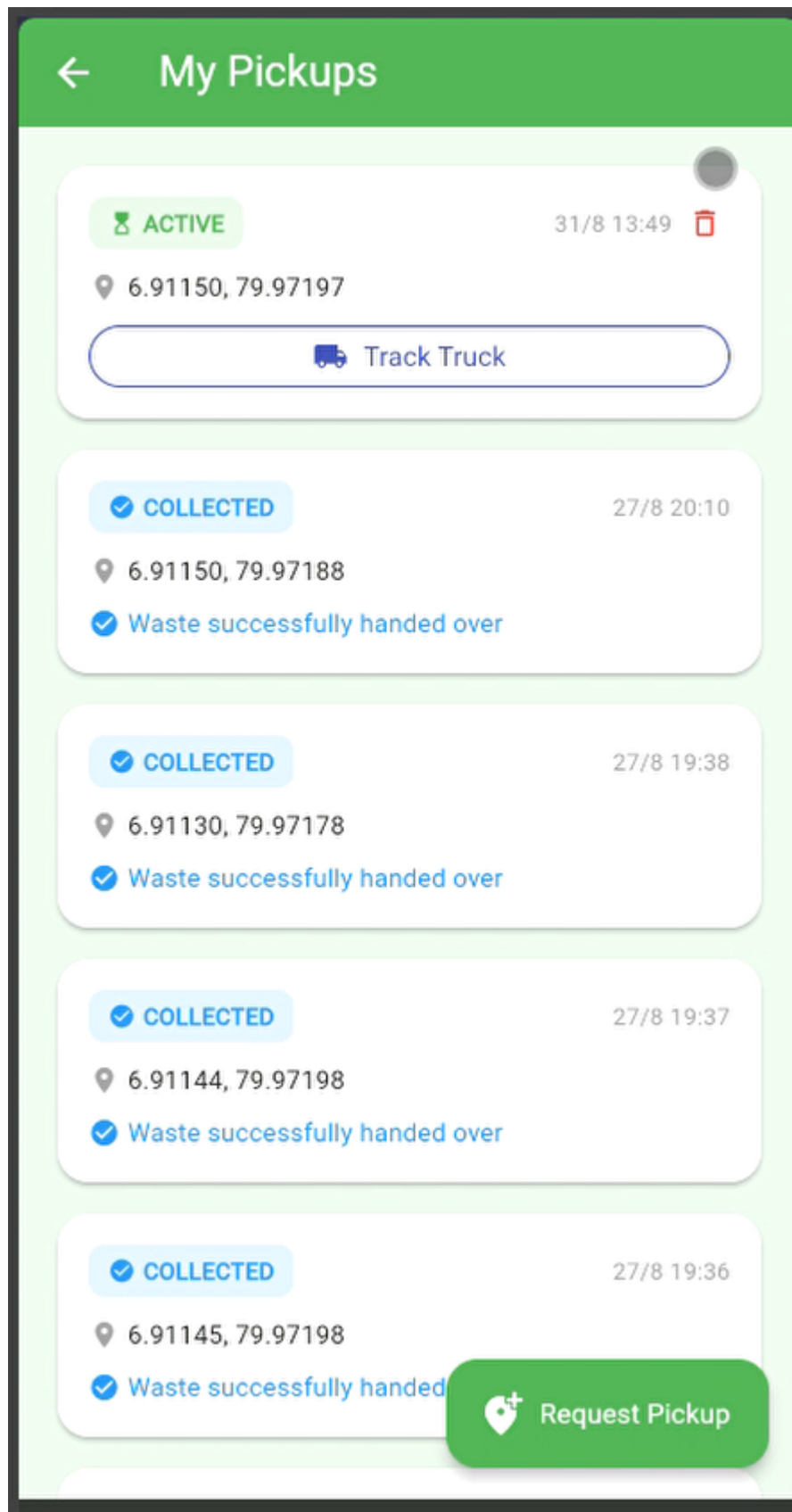
Appendix A – Extended test evidence and screenshots

- Resident creates a pickup request.
- Driver sees the pickup request on the map.
- Driver starts the trip.
- Resident observes live driver movement.
- “Truck is here” notification.
- Nearest-truck display before and after the relative positions change.
- Critical smart bin appears in red on the driver map.
- Driver views/selects the critical bin.
- Pickup/collection completion.
- Administrator deactivates a user.
- Recovery request submitted.
- Administrator re-enables the user.
- OTP registration.
- Password reset.

Appendix B – Academic integrity and AI use disclosure

Generative-AI assistance was used during drafting, editing, organisation and language refinement of parts of this thesis. Source documents and project evidence were used as the basis for technical claims. The candidate must verify every technical statement, reference, test result, screenshot and conclusion before submission and must complete any additional AI-use disclosure required by SLIIT or the module coordinator.





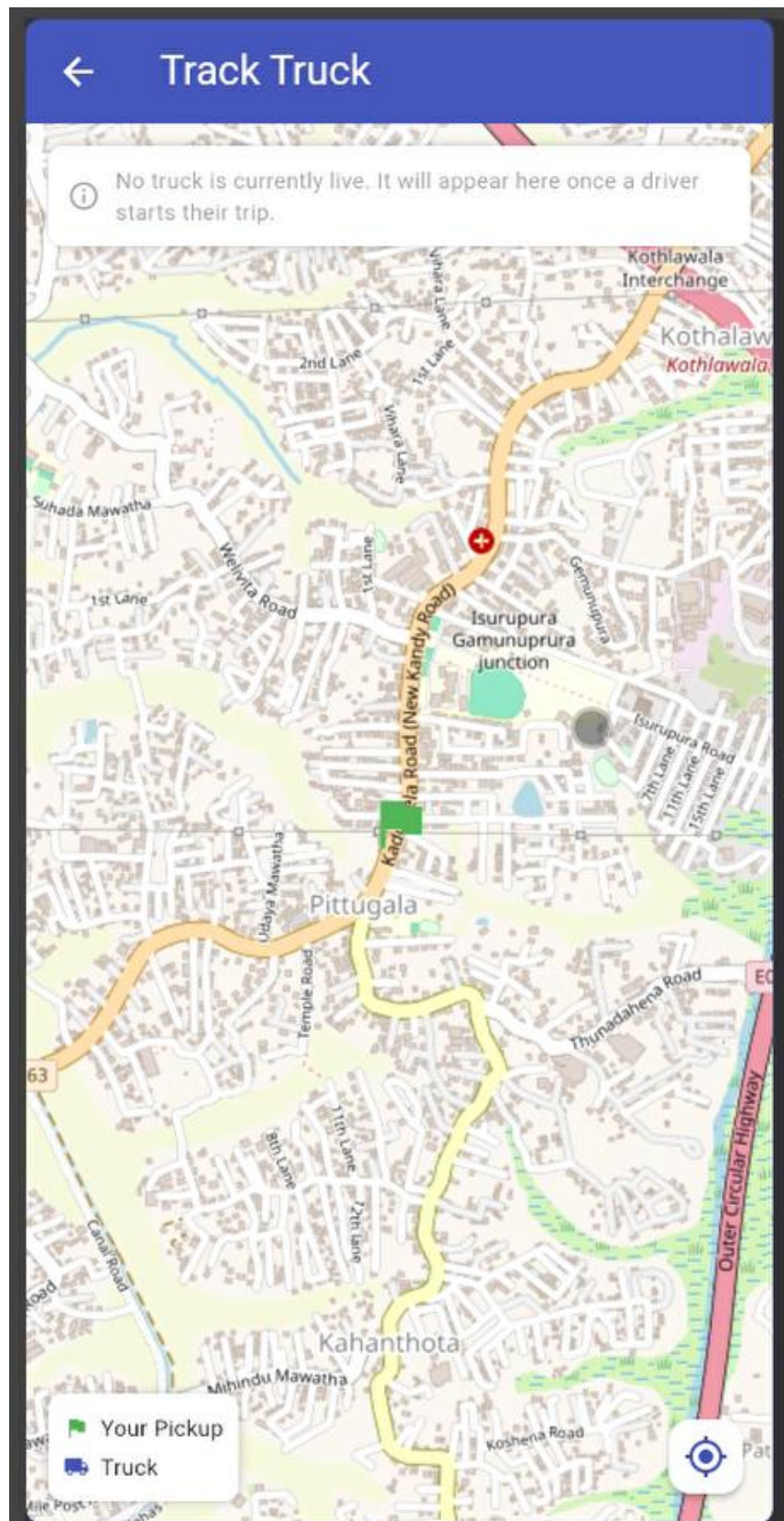


Figure A.1 – Resident creates a waste pickup request

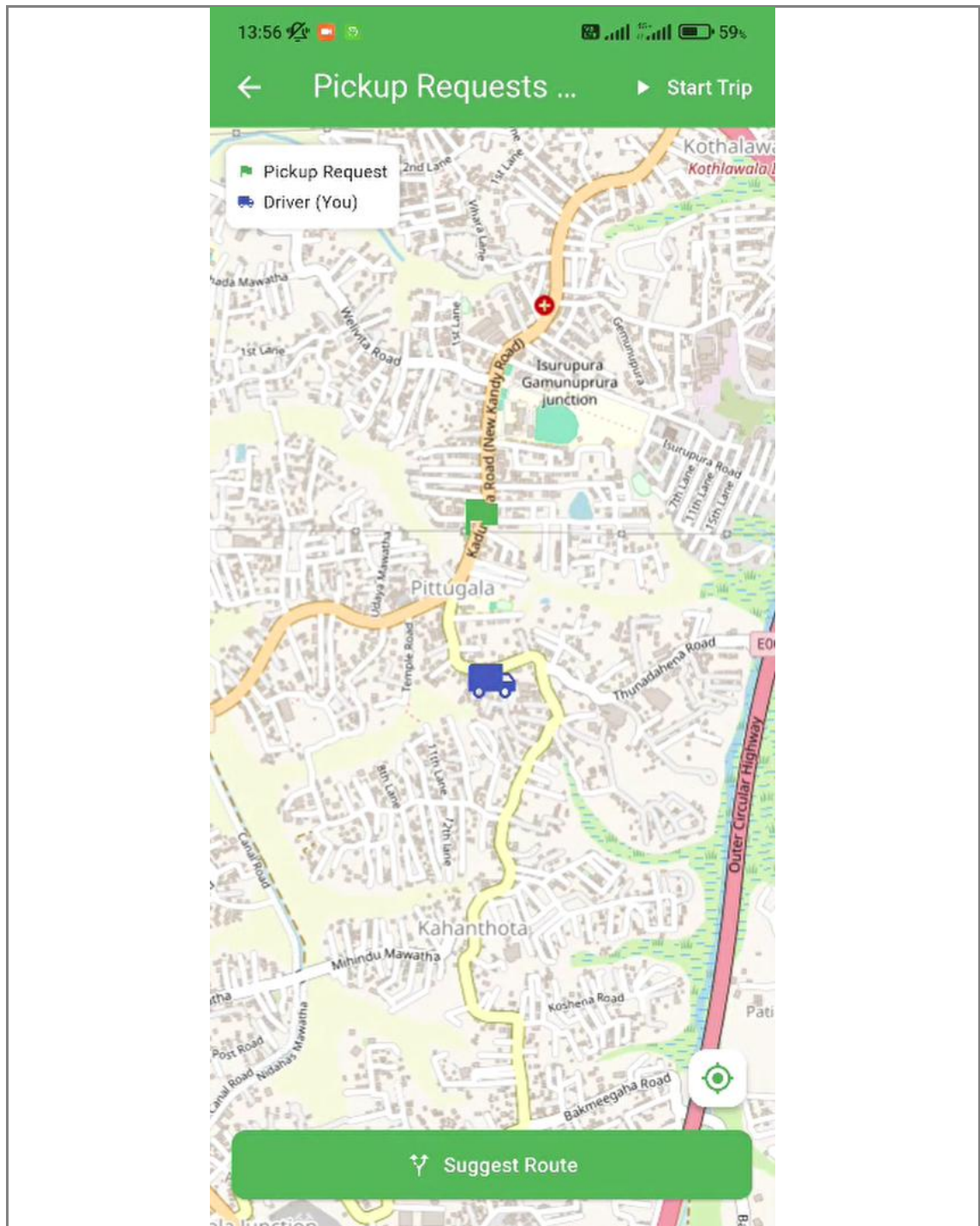


Figure A.2 – Driver views the resident pickup request on the map

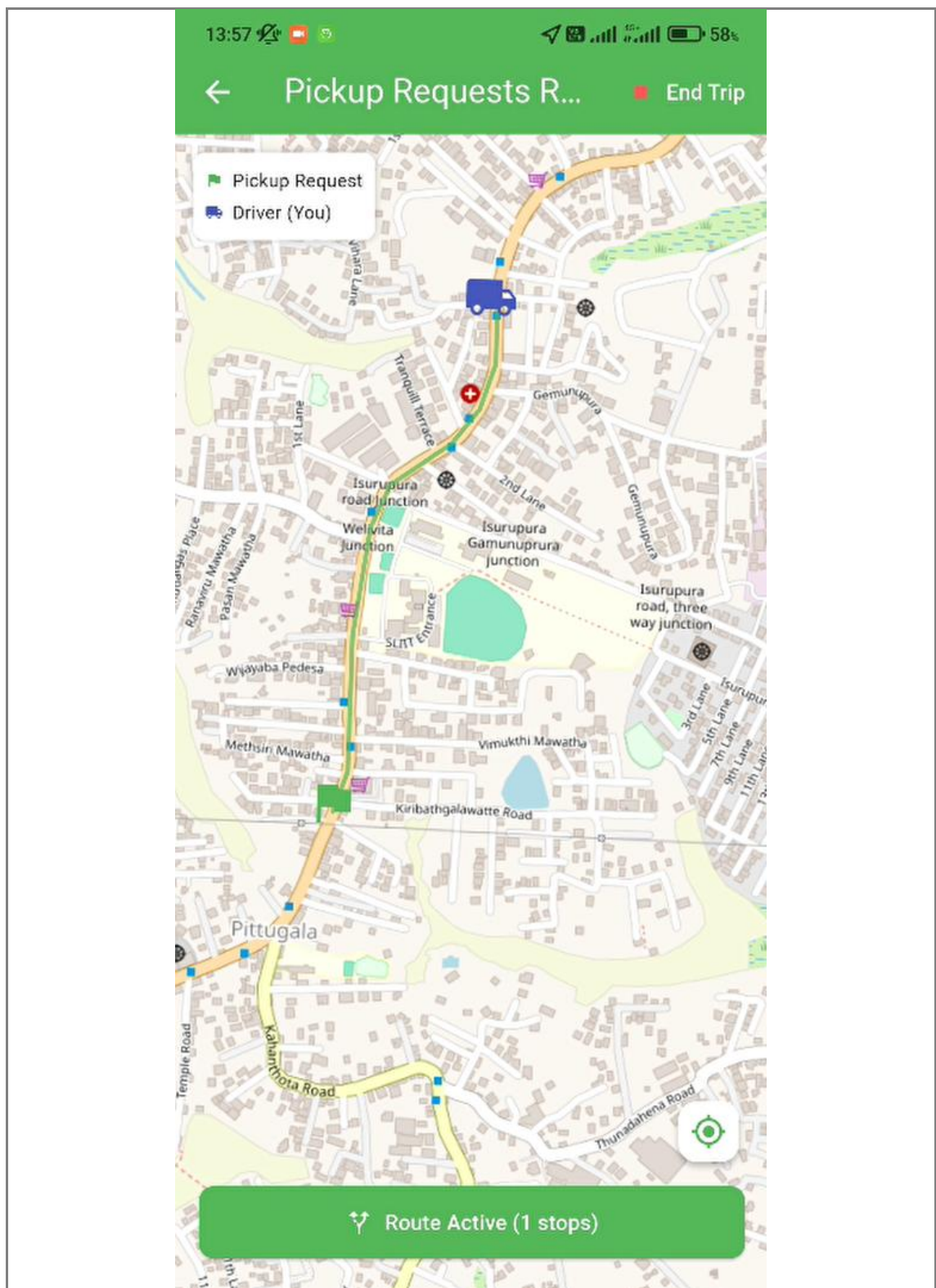


Figure A.3 – Driver starts the trip

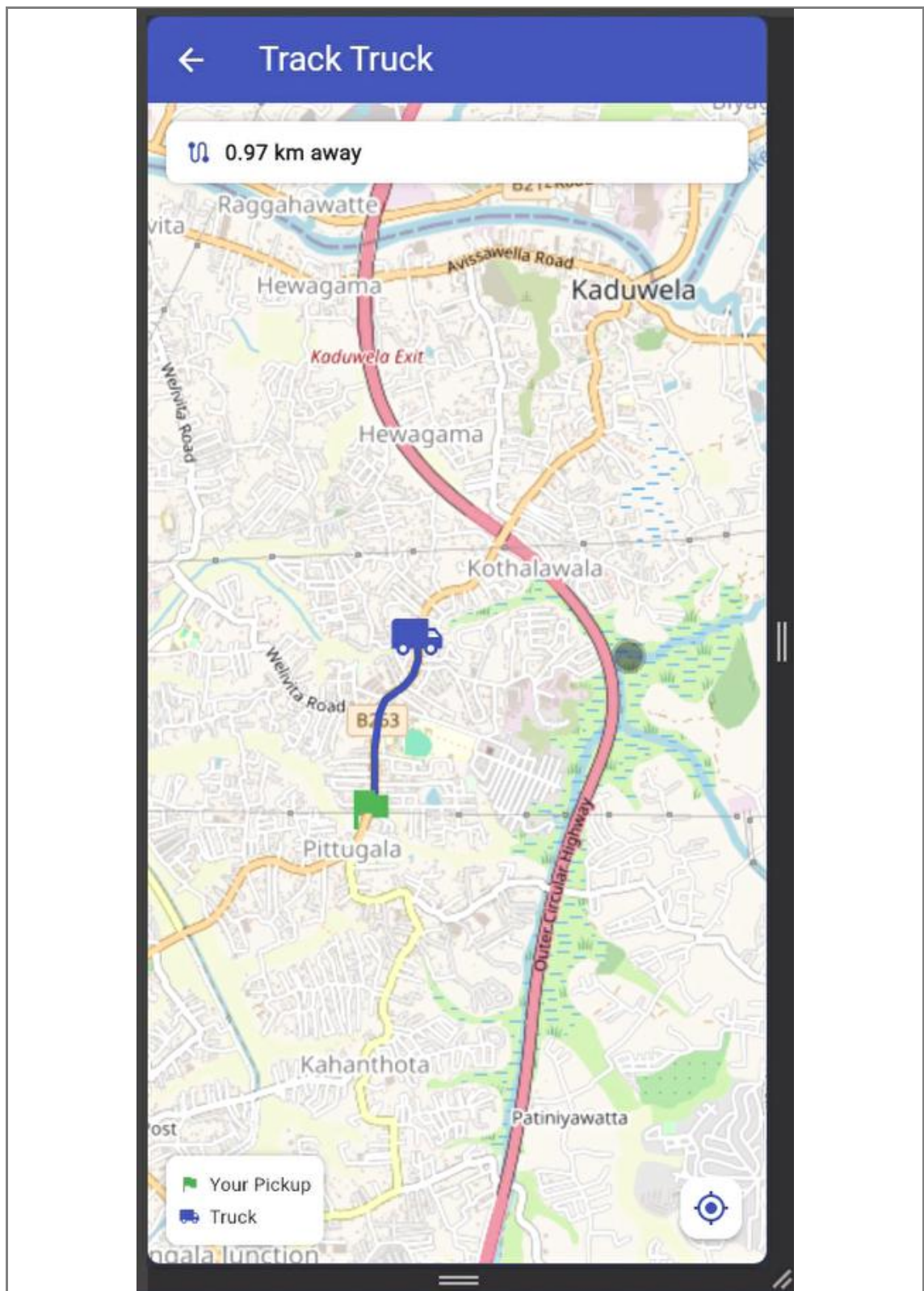


Figure A.4 – Resident views the driver's live movement

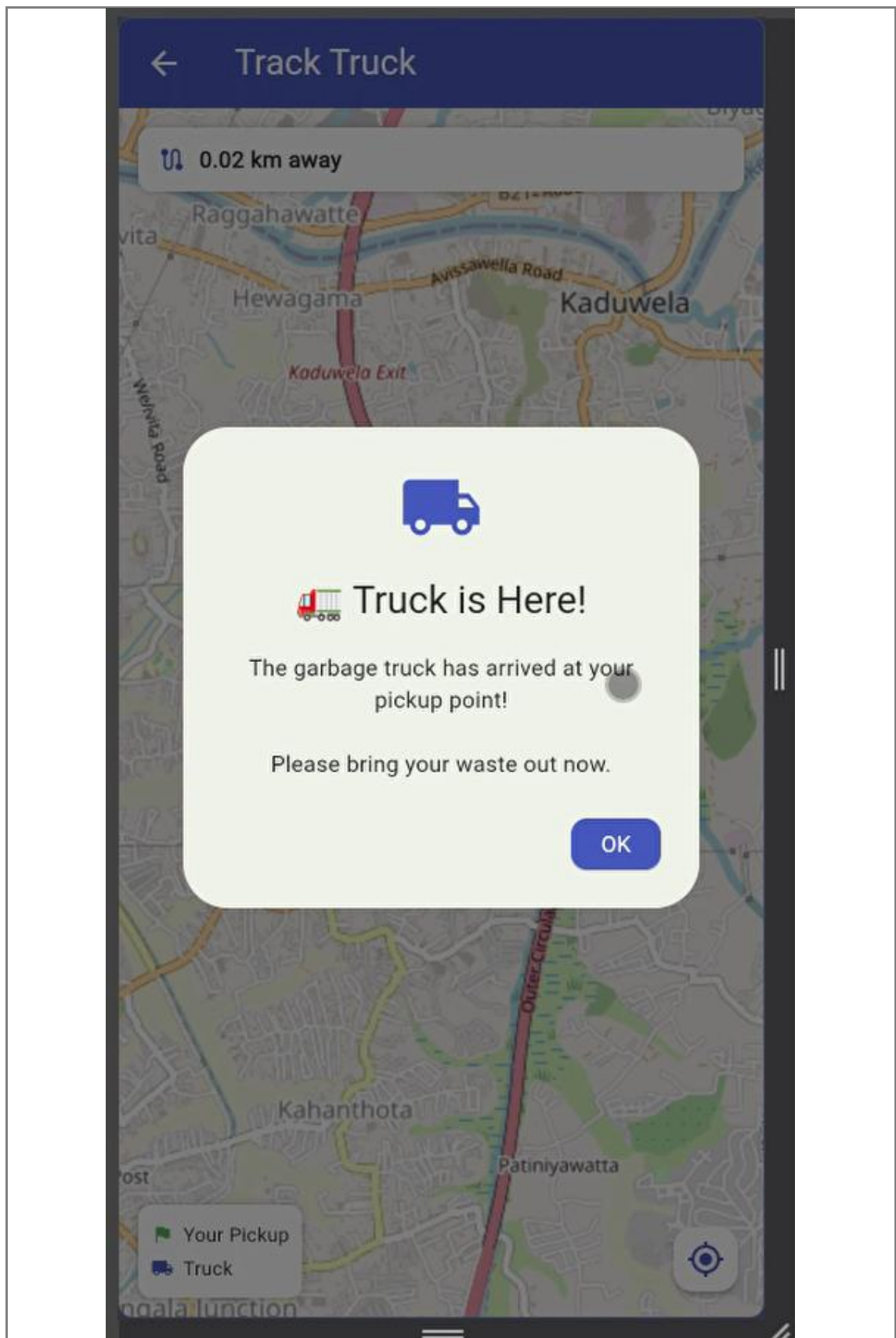


Figure A.5 – “Truck is here” arrival notification

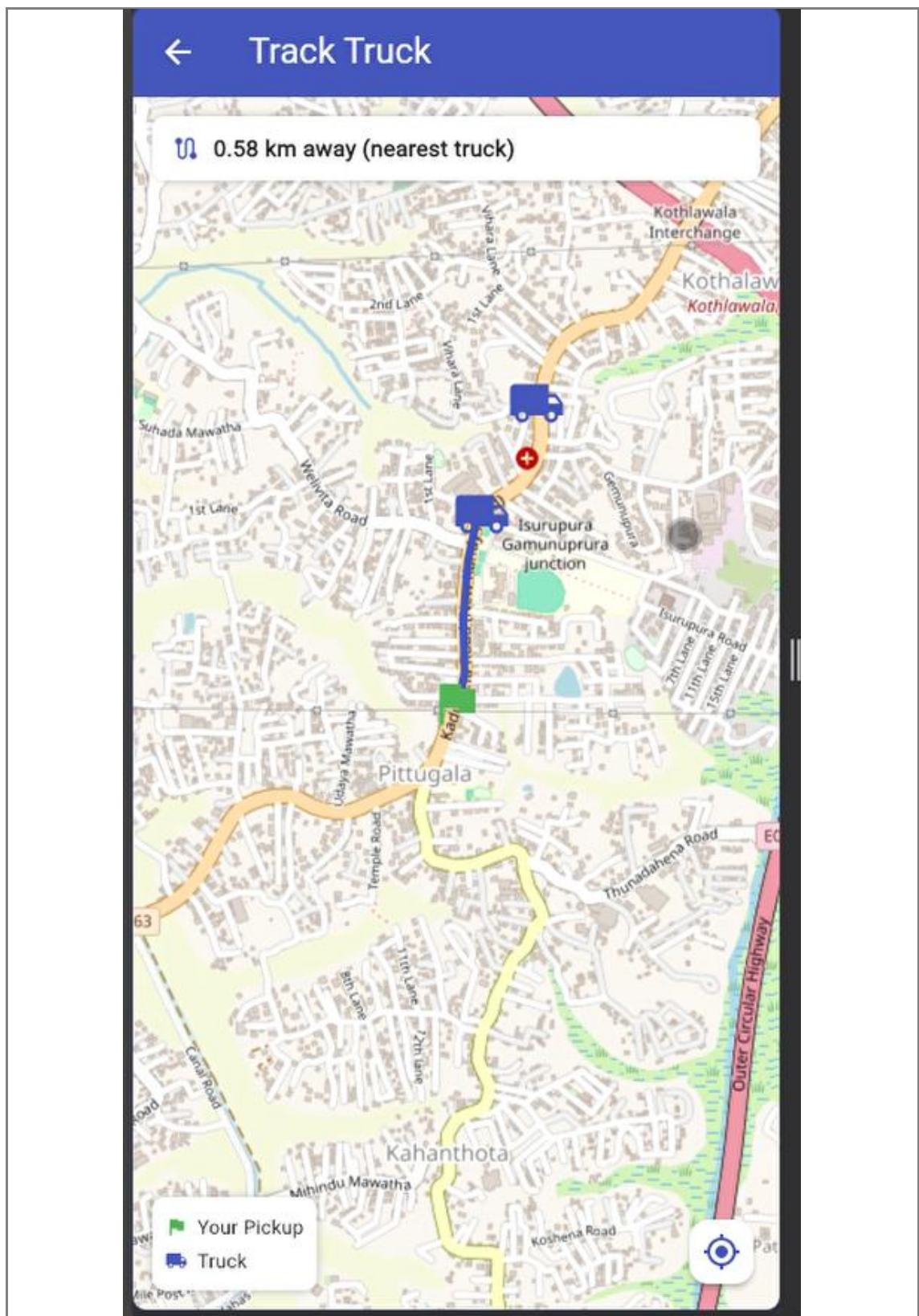
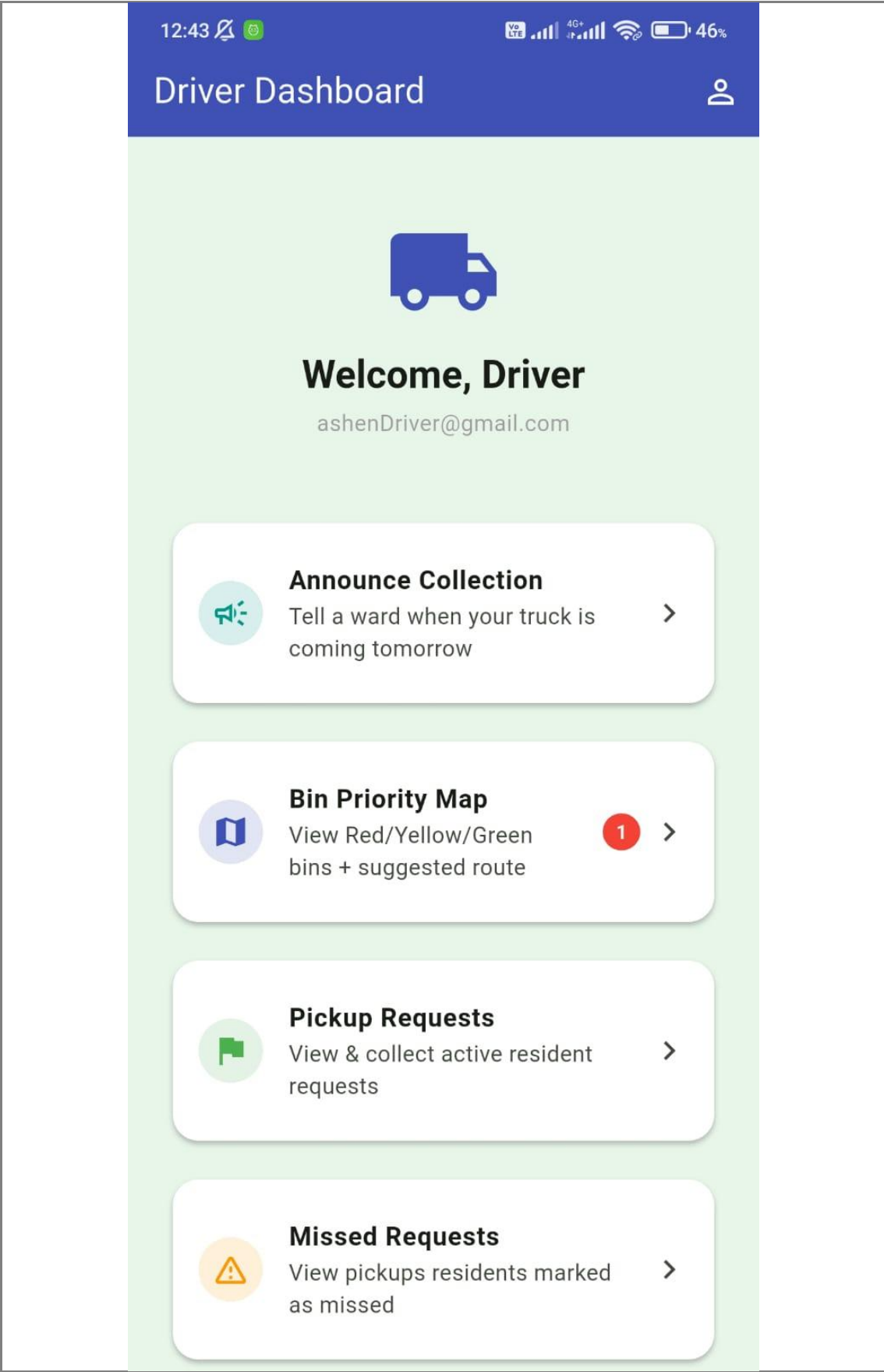


Figure A.6 – Nearest-truck display and dynamic nearest-truck update



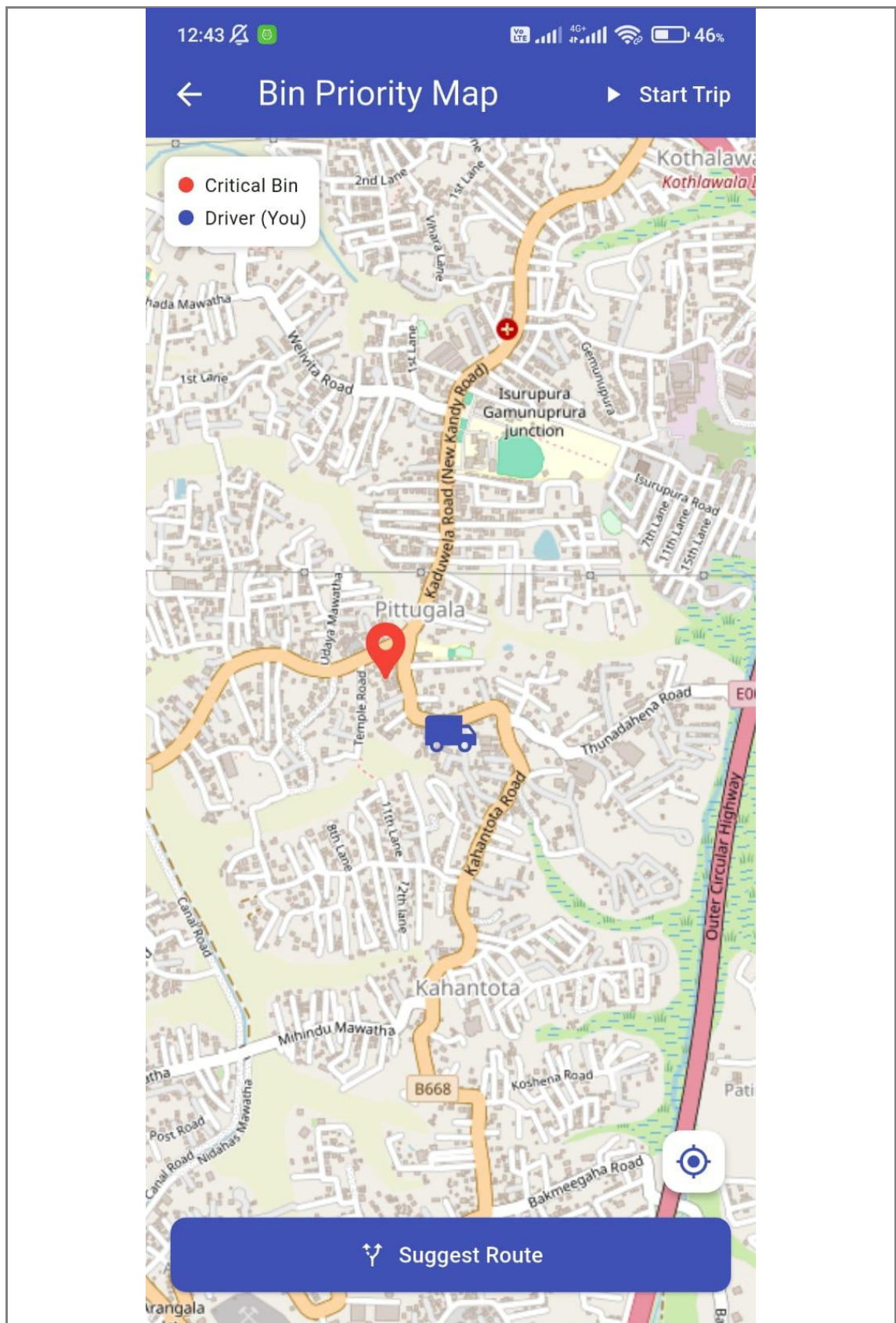


Figure A.7 – Critical smart bin displayed in red on the driver map

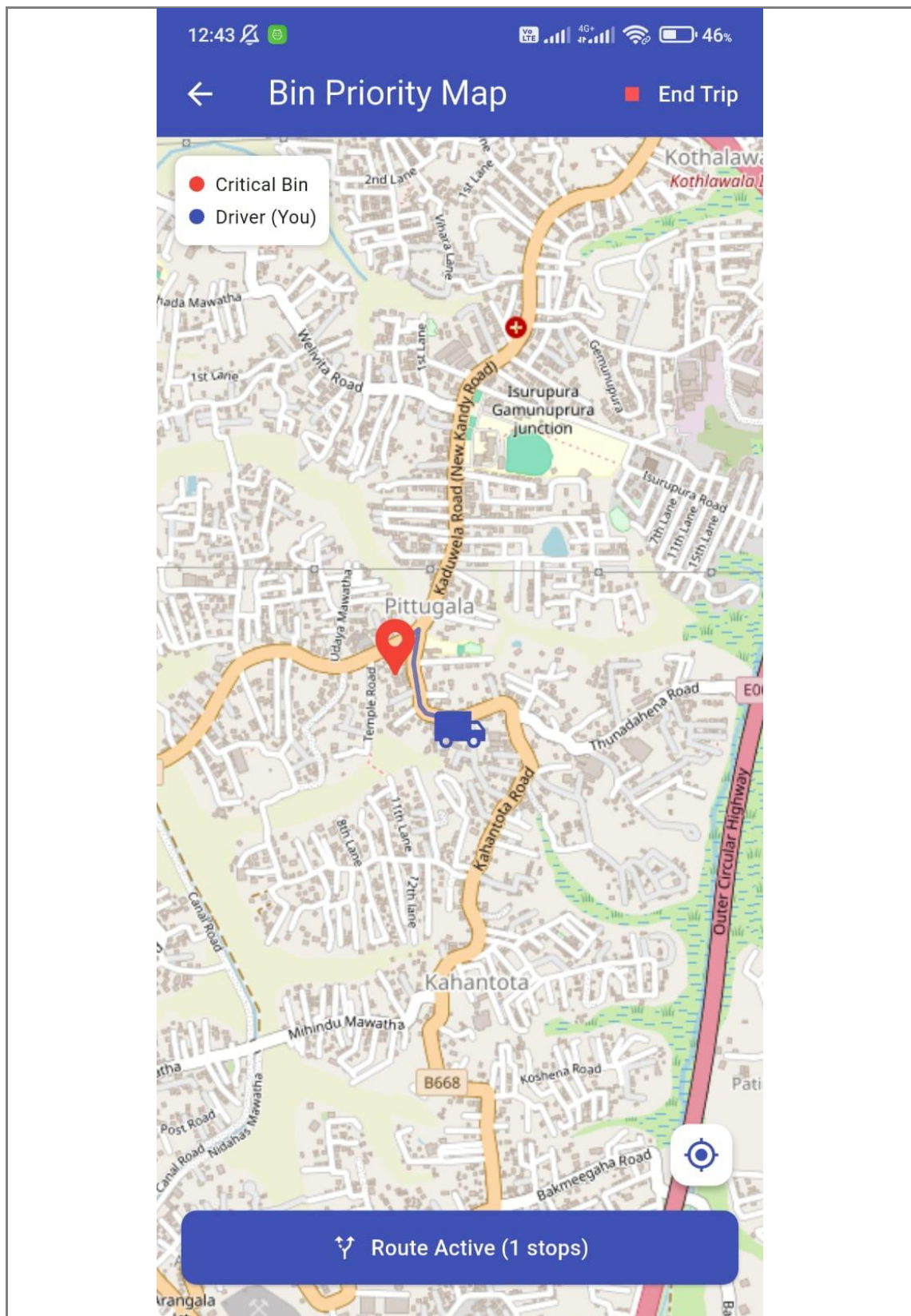


Figure A.8 – Driver views/selects the critical smart bin

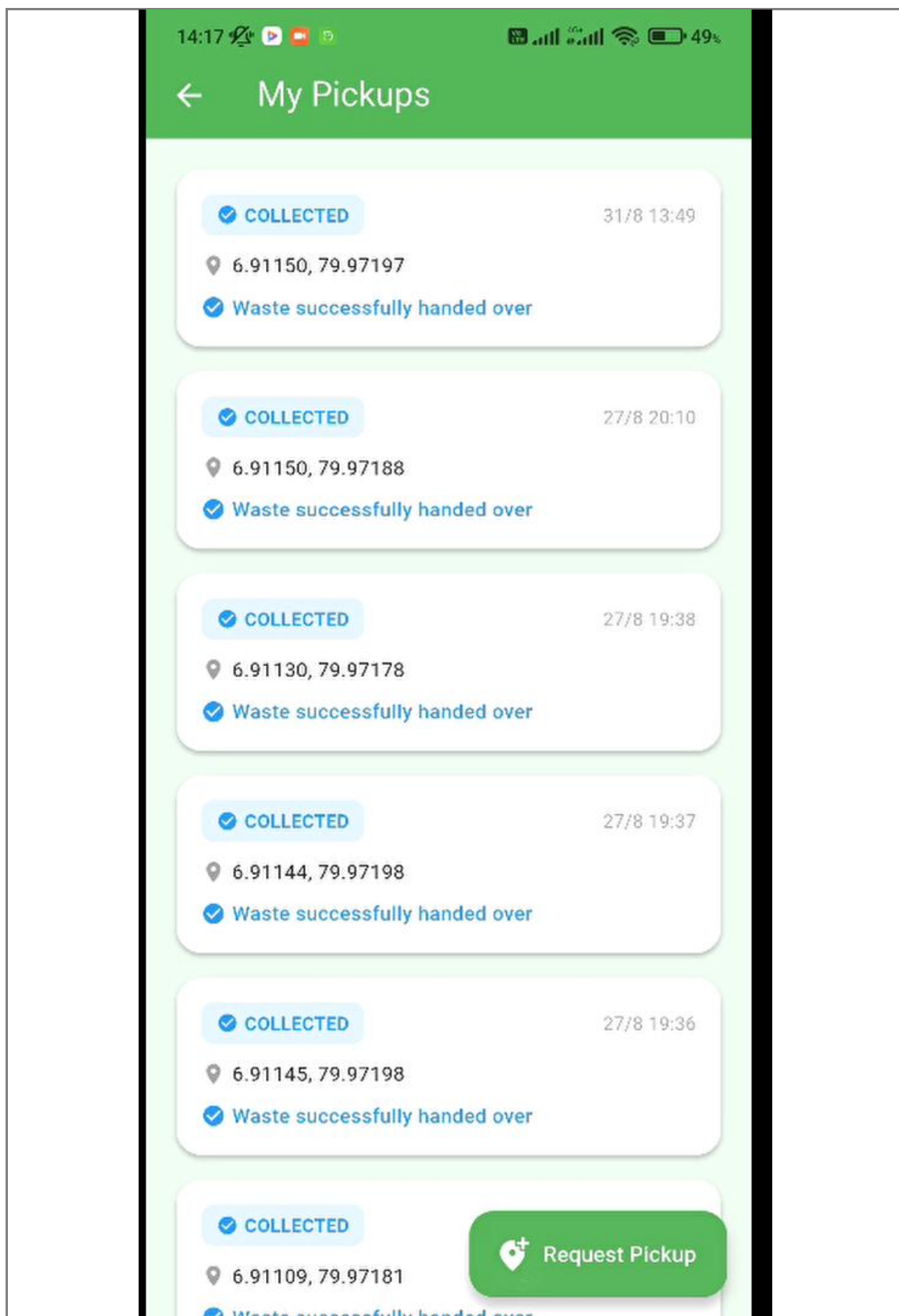


Figure A.9 – Pickup arrival / collection completion status

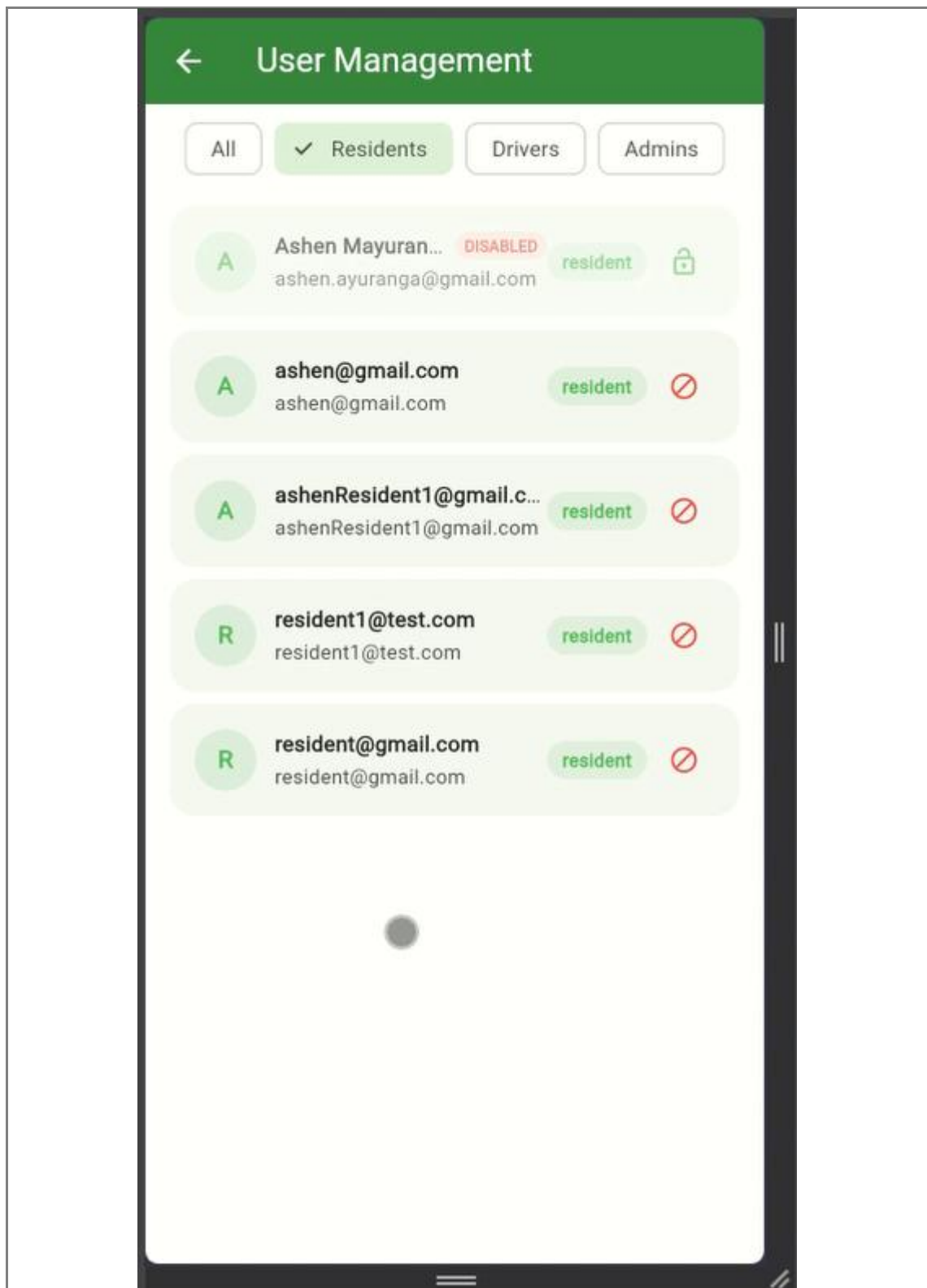


Figure A.10 – Administrator deactivates a user account

14:38

38%



Account Disabled

Your account has been disabled by an administrator.
You will not be able to sign in until it is re-enabled.

 Contact Admin

OK

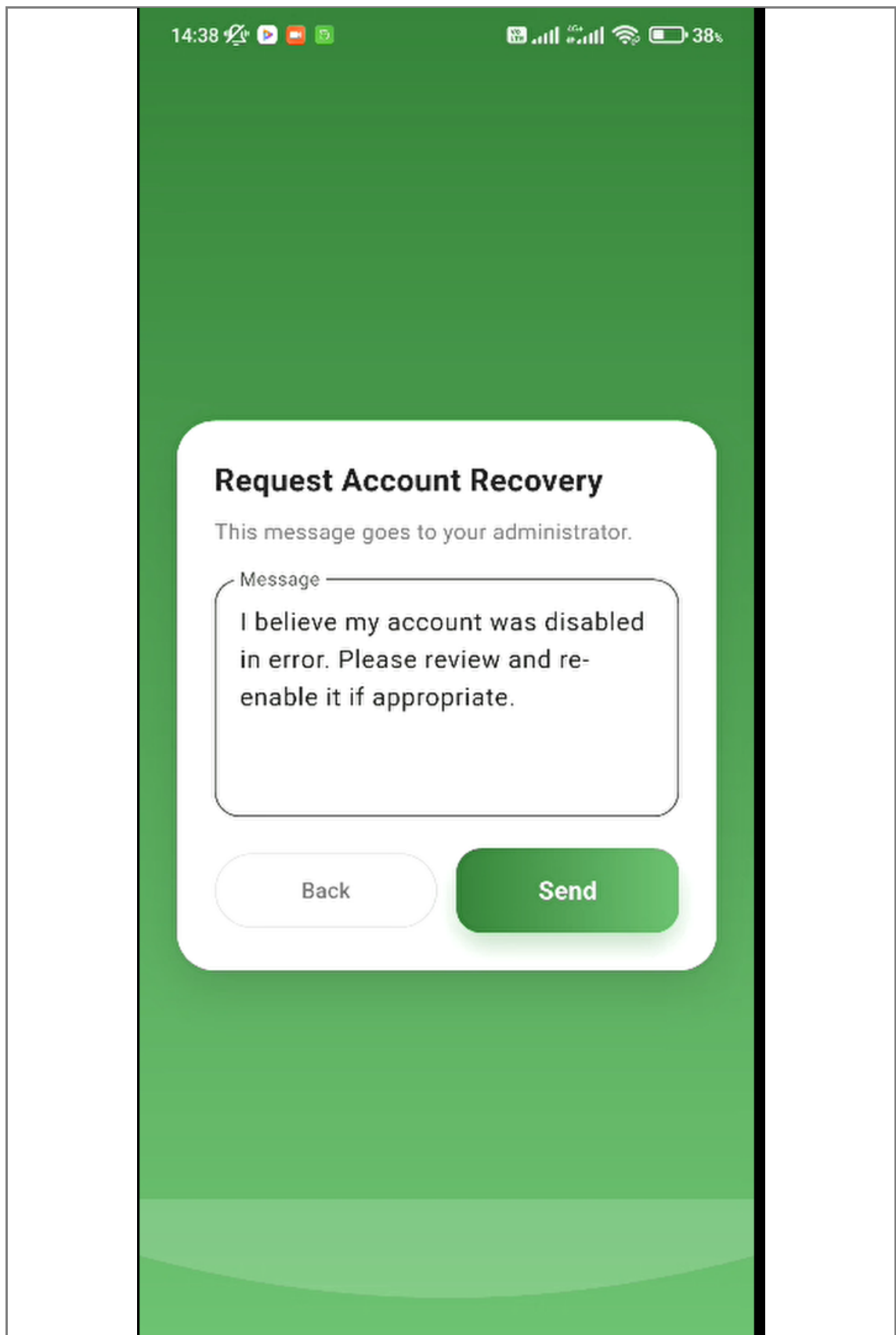
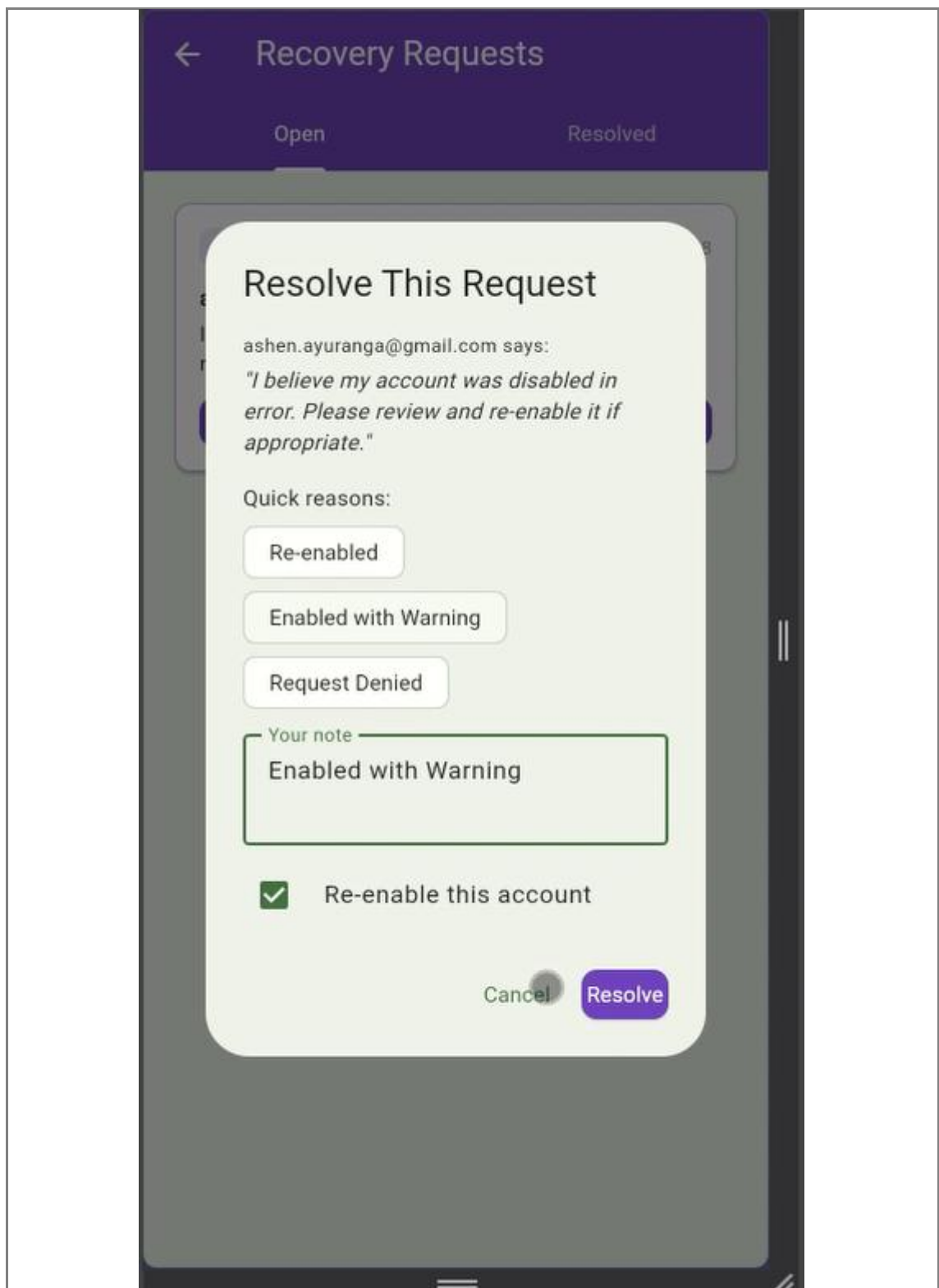


Figure A.11 – User submits an account recovery request



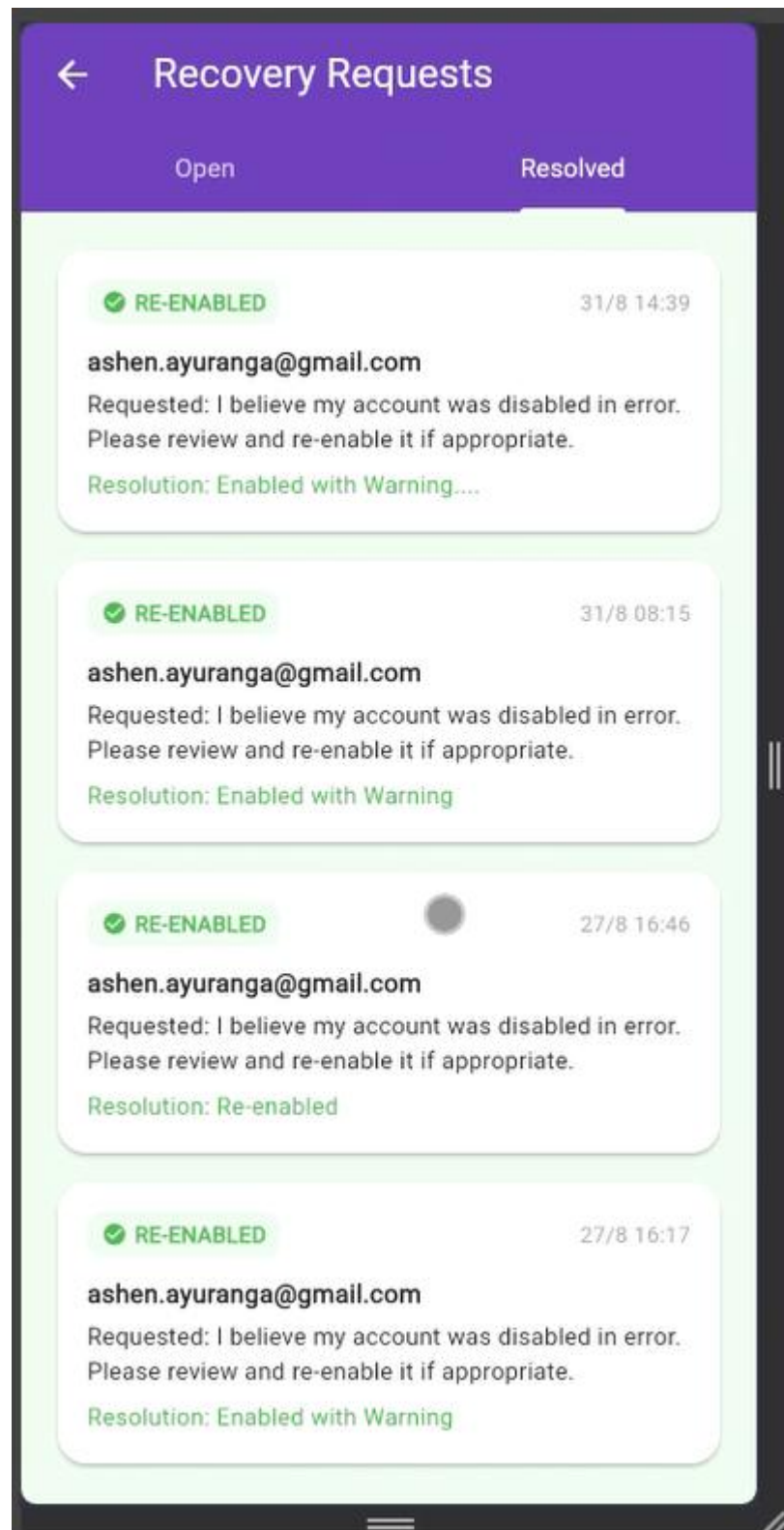
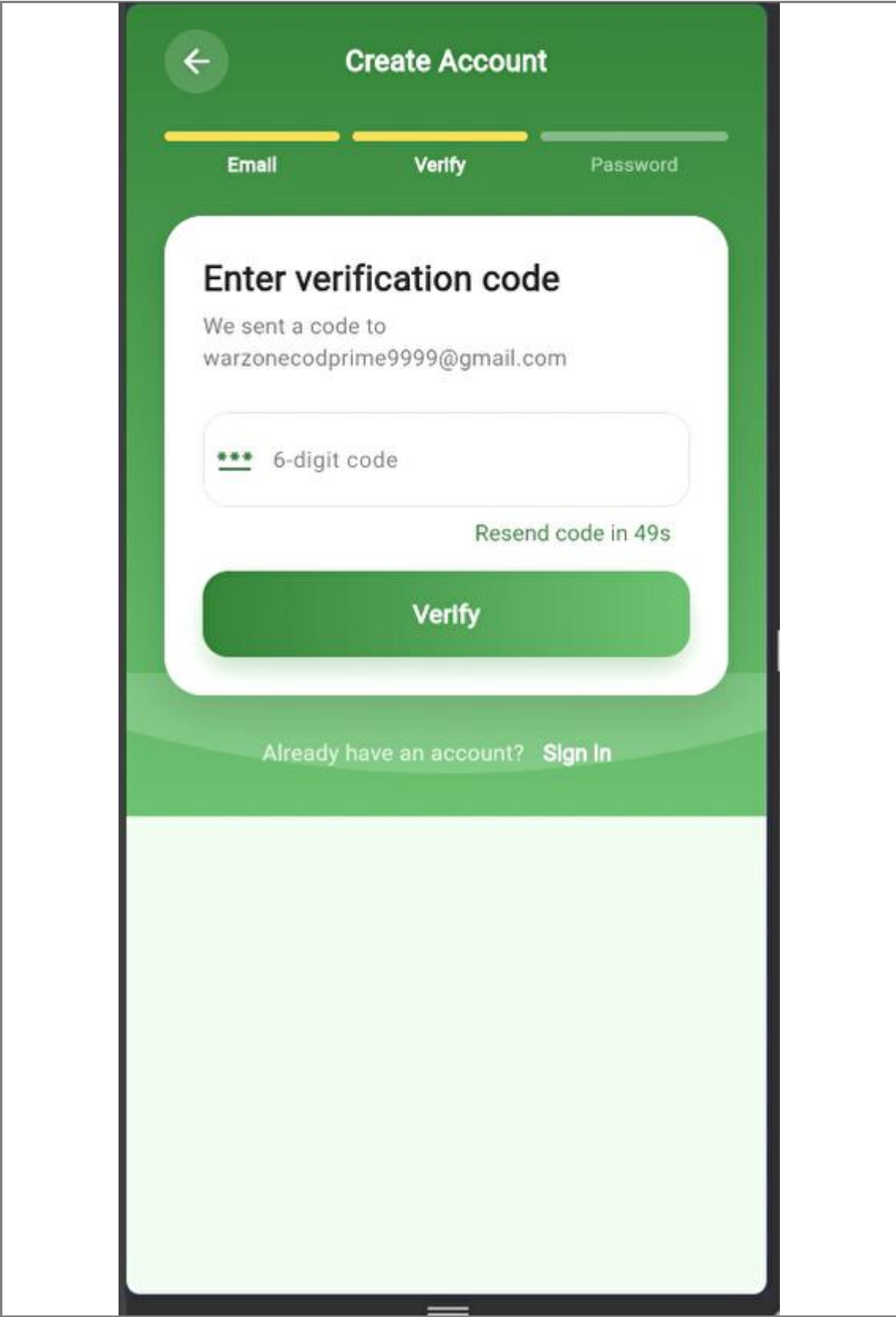


Figure A.12 – Administrator re-enables the user account





GreenSweep App

to me ▾

2:52 PM (0 minutes ago)



Hello,

Your GreenSweep verification code is:

537118

This code will expire in 10 minutes minutes.

If you did not request this code, please ignore this email.

Best regards,
GreenSweep Team



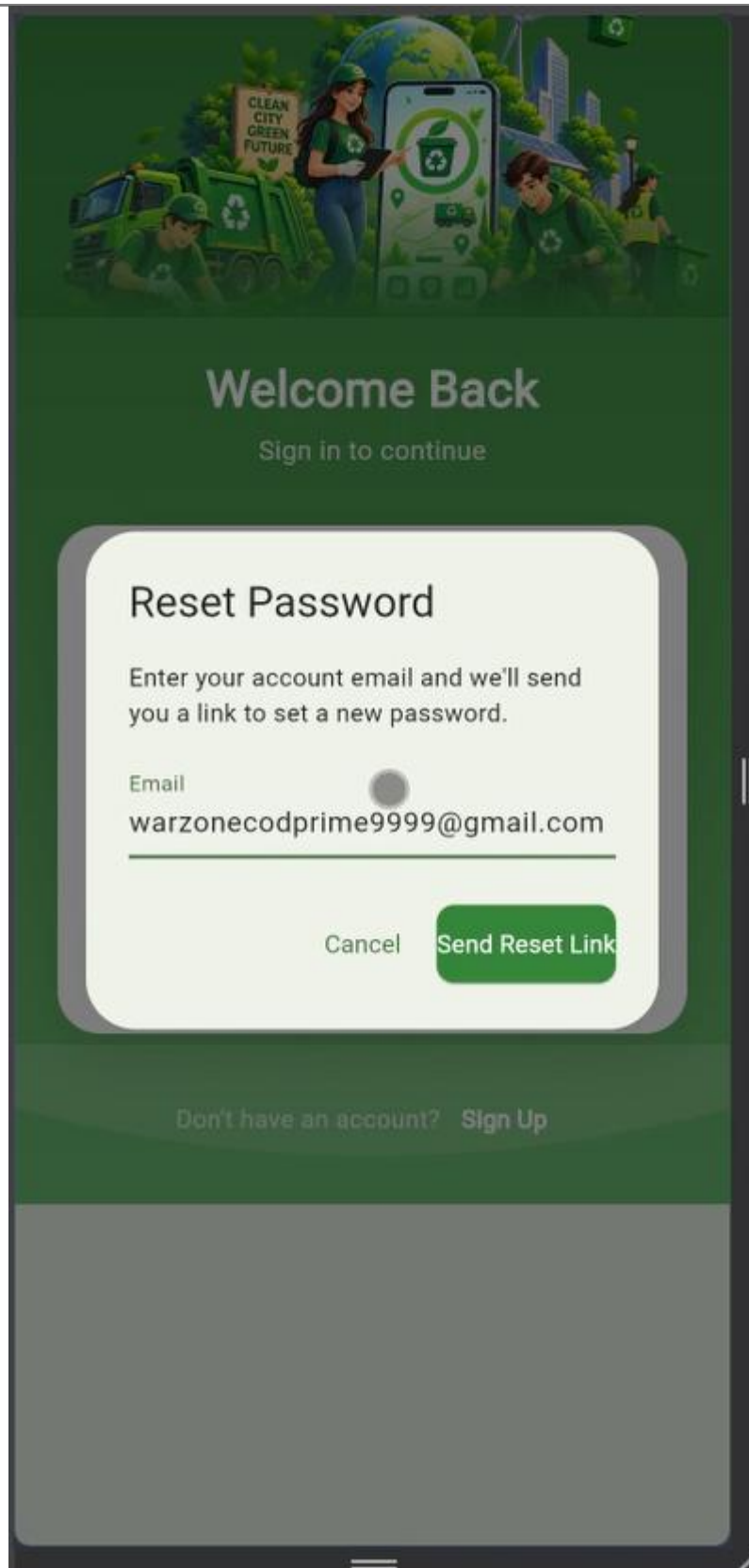
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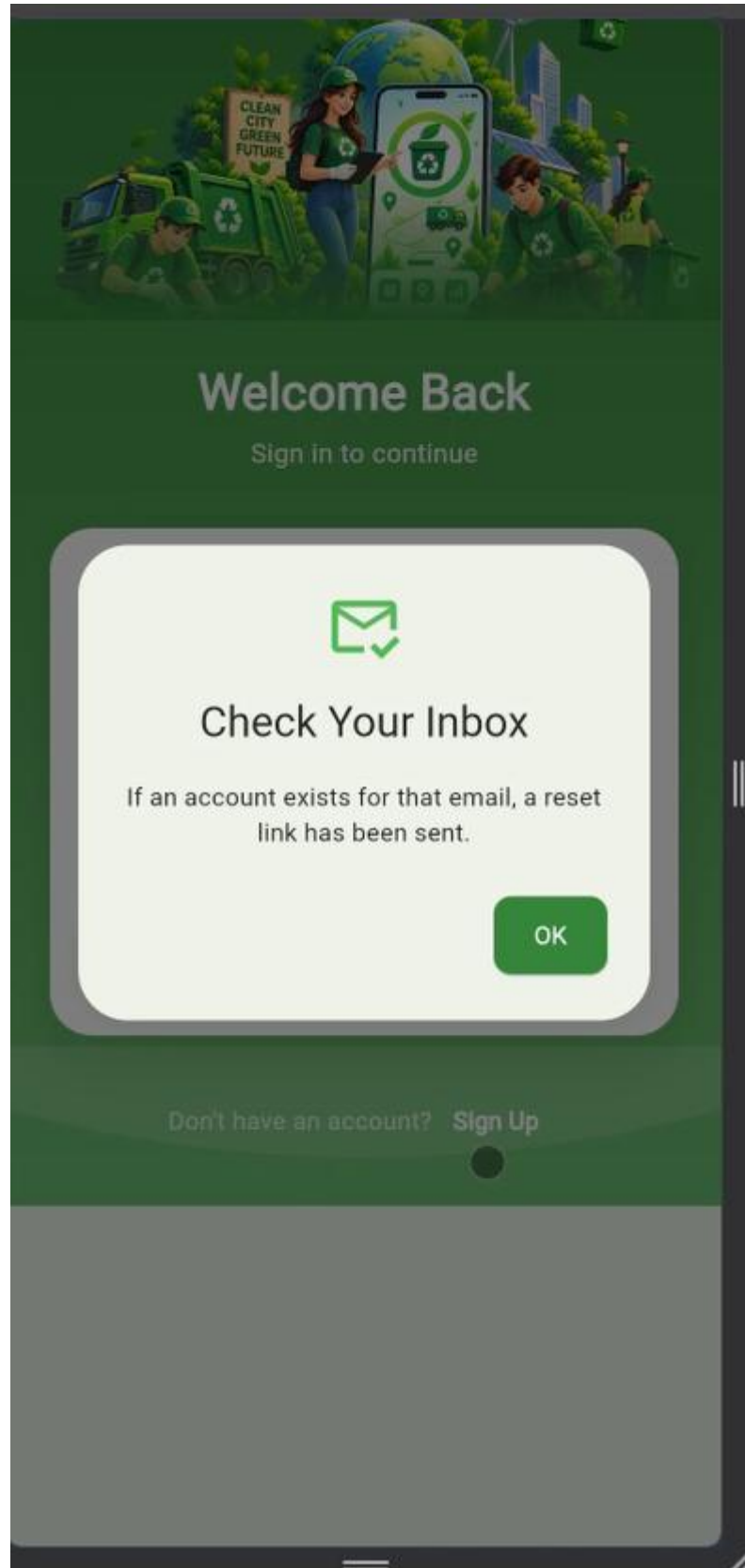
↩ Reply

➦ Forward



Figure A.13 – User registration and OTP verification





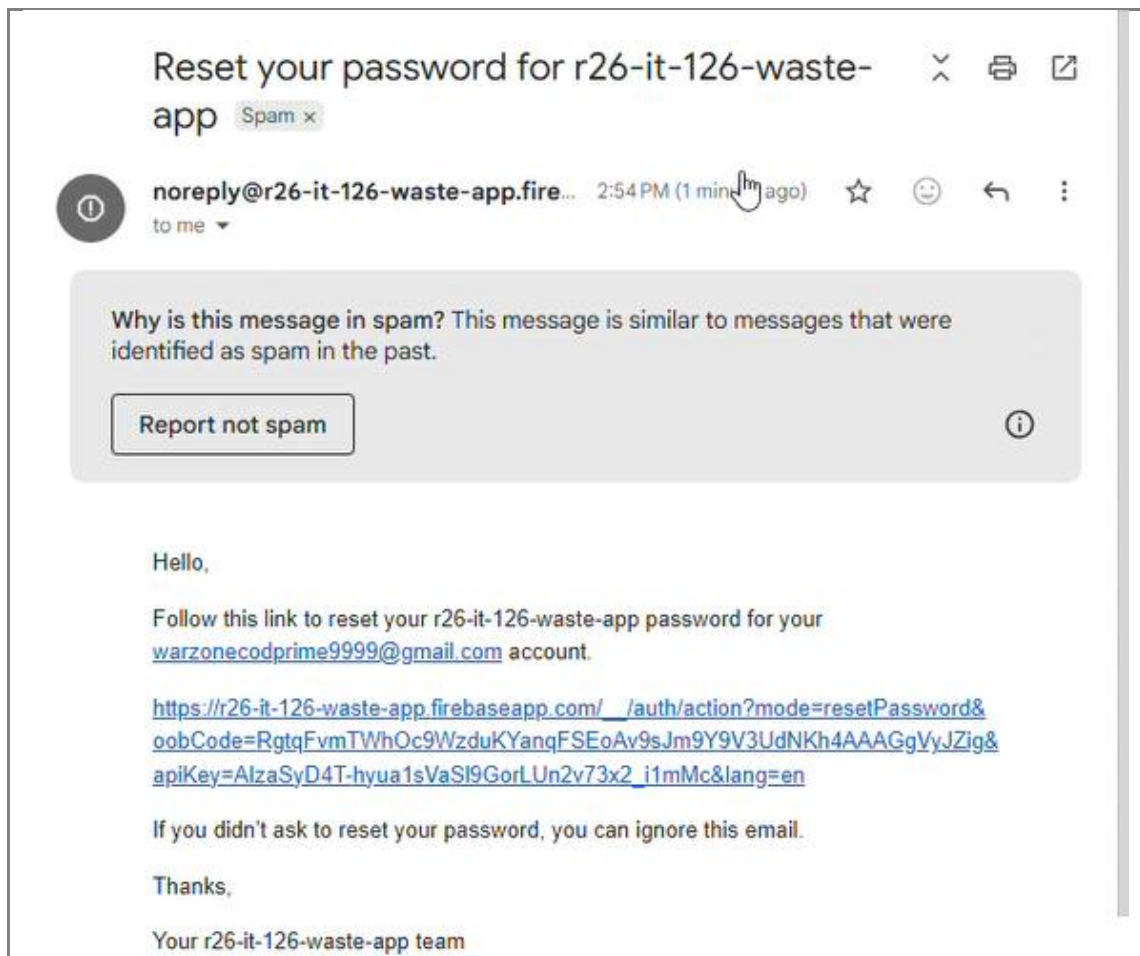


Figure A.14 – Password reset screen / successful password reset