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Smart Food Waste Rescue Hub Application: IOT-Enabled Platform for Surplus Food Redistribution

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Abstract— Food waste is a critical global challenge with profound environmental, economic, and social implications. Over 1.3 billion tons of edible food are discarded annually by restaurants, grocery stores, hostels, and households, while concurrently 828 million people face chronic food insecurity. This paper presents the Smart Food Waste Rescue Hub Application — a comprehensive digital platform designed to mitigate food waste by facilitating efficient redistribution of surplus food from donors to Non-Governmental Organizations (NGOs), shelters, and beneficiaries. The proposed system leverages modern web technologies integrated with Internet of Things (IoT) sensors to ensure transparency, traceability, and food safety throughout the entire donation lifecycle. The application is developed using Next.js 14 and Tailwind CSS for a responsive and accessible frontend, with Firebase serving as the scalable backend infrastructure handling authentication, real-time Firestore database management, and cloud storage. A critical innovation is the integration of an ESP32 microcontroller equipped with DHT22 temperature/humidity sensors and MQ-series gas sensors, which continuously monitor environmental conditions during food storage and transit, automatically triggering alerts to stakeholders when predefined safety thresholds are breached. A 3-month pilot deployment across 15 restaurants and 8 NGOs in Coimbatore rescued 847 kg of food, saved 2.19 tons of CO_2 equivalent, achieved 96.8% alert accuracy, and reduced average pickup time by 42%. The platform presents a sustainable, scalable blueprint for bridging food surplus and scarcity while promoting environmental sustainability.

Keywords — *Food waste management; IoT; ESP32; Firebase; Next.js; Food safety monitoring; Surplus redistribution; Environmental sustainability; Geo-aware logistics*

I. INTRODUCTION

Global food waste exceeds 1.3 billion metric tons annually, representing approximately one-third of all food produced for human consumption. Simultaneously, the Food and Agriculture Organization (FAO) reports that 828 million people suffer from chronic hunger worldwide. This paradox of abundance and scarcity is exacerbated by inadequate food redistribution infrastructure, lack of real-time safety monitoring, and poor coordination between food donors and recipient organizations [1].

Restaurants contribute approximately 22% of global food waste, while households account for 61%, and retail establishments 14% [2]. The decomposition of organic waste in landfills contributes 8–10% of global greenhouse gas (GHG) emissions, making food waste a significant driver of climate change. Beyond environmental consequences, the economic cost of food waste is estimated at $1 trillion annually, with developing nations disproportionately affected.

Existing food rescue platforms such as Too Good To Go, OLIO, and Flashfood address components of this challenge but lack critical capabilities: real-time IoT-based food safety monitoring during storage and transit, comprehensive NGO/shelter integration, and geo-aware logistics optimization. Current platforms predominantly facilitate peer-to-peer sharing without ensuring that food remains safe for consumption throughout the redistribution chain [3].

This paper proposes the Smart Food Waste Rescue Hub Application, a novel platform that integrates: (1) a Next.js 14 progressive web application frontend with Tailwind CSS responsive design; (2) Firebase-based scalable backend with Firestore, Cloud Functions, and real-time authentication; and (3) an ESP32 IoT node network equipped with DHT22 and MQ-135 sensors for continuous environmental monitoring. The system automatically alerts stakeholders when food safety thresholds are violated, ensuring only safe, high-quality food reaches vulnerable beneficiaries.

The primary contributions of this research are:

• Real-time IoT environmental monitoring with automated spoilage detection and multi-channel alert dispatch

• Geo-aware volunteer and NGO matching using the Haversine distance formula for optimal logistics

• Scalable multi-stakeholder web platform supporting donors, NGOs, volunteers, and administrators

• Empirical validation through a 3-month pilot deployment demonstrating significant operational improvements

• Carbon footprint calculator and analytics dashboard for sustainability impact assessment

• Blockchain-enabled donation traceability and immutable audit logging for enhanced transparency and trust among stakeholders

• AI-driven shelf-life prediction and smart expiry estimation using historical sensor telemetry and environmental condition analysis

Fig. 1. Global Food Waste Flow — Sources, Landfill Impact, and Hunger Statistics (FAO 2025)

II. LITERATURE REVIEW

Existing food waste management solutions can be categorized into three broad classes: consumer-facing mobile applications, NGO coordination portals, and IoT-based smart waste monitoring systems. This section reviews representative works and identifies the critical research gap addressed by the proposed system.

A. Mobile Application Platforms

Too Good To Go [3] operates in 17 countries, connecting consumers with restaurants selling surplus food at reduced prices via a React Native application. While commercially successful with over 80 million users, the platform lacks any IoT safety monitoring and does not integrate with NGOs or charitable organizations, limiting its social impact. OLIO [4], a peer-to-peer food sharing application, similarly focuses on individual users without NGO-level coordination or safety verification mechanisms.

Flashfood connects grocery stores to consumers for discounted near-expiry products but operates exclusively within retail ecosystems without addressing restaurant or household waste. FoodCloud provides a web portal connecting businesses with charities but relies entirely on manual safety checks with no technological food quality assurance.

B. IoT-Based Food Monitoring Systems

Khan et al. [5] demonstrated an IoT-based agro-food waste management system utilizing ultrasonic fill-level sensors in smart bins, achieving 89% waste prediction accuracy. However, this system focused exclusively on bin capacity monitoring rather than food quality during redistribution transit. Nurhakim [6] developed an ESP32-Firebase dashboard for environmental parameter monitoring, providing foundational architecture for the IoT integration approach adopted in this research.

Recent research in smart food distribution [11] explored ML-based shelf-life prediction using initial food conditions but lacked the complete ecosystem integration required for end-to-end food redistribution. IoT food monitoring systems reviewed in IEEE Xplore [2] predominantly focus on agricultural supply chain monitoring rather than urban food rescue operations, leaving a significant gap for city-scale surplus redistribution platforms.

C. Research Gap Analysis

A systematic review of existing literature reveals that no published platform combines: (i) web-scalable multi-stakeholder architecture, (ii) real-time IoT food safety monitoring during transit, (iii) geo-aware NGO/volunteer logistics, and (iv) automated safety alerting with blockchain audit trails. Table I presents a structured comparison of existing systems against the proposed solution.

TABLE I. Comparison of Existing Food Waste Management Systems

System	Tech Stack	IoT Mon.	Alerts	NGO Intgr.	Geo-Sched.
Too Good To Go	React Native	None	No	No	Basic
OLIO	Native Mobile	None	No	Partial	No
Flashfood	Web App	None	No	No	Store-based
FoodCloud	Web Portal	None	No	Yes	Manual
Proposed System	**Next.js/Firebase/ESP32**	**Temp/Hum/Gas**	**Real-time**	**Full**	**Advanced**

Source: Authors' compilation from literature review (2025)

III. SYSTEM ARCHITECTURE

The Smart Food Waste Rescue Hub Application employs a three-tier architecture comprising a Presentation Layer (Next.js/Tailwind CSS), Application Layer (Firebase GCP), and IoT Layer (ESP32 sensor nodes). Data flows bidirectionally across these tiers: donor food listings propagate downward to trigger IoT monitoring, while sensor telemetry propagates upward through Cloud Functions to notify stakeholders and update the operational dashboard.

The Presentation Layer provides an intuitive and responsive user interface for donors, NGOs, volunteers, and administrators through web and mobile-compatible dashboards. The Application Layer, hosted on Firebase Google Cloud Platform (GCP), manages authentication, real-time database synchronization, cloud storage, and serverless event-driven processing. Firebase Cloud Functions continuously analyze incoming sensor telemetry and execute automated decision-making workflows for spoilage detection and emergency alert generation.

The IoT Layer consists of ESP32 microcontroller nodes integrated with DHT22 temperature-humidity sensors and MQ-135 gas sensors for environmental condition monitoring. These devices periodically transmit telemetry data to Firebase Firestore through WiFi communication, while the SIM800L GSM module acts as a backup communication channel during network outages. Geo-location services integrated into the system utilize the Haversine distance formula to identify the nearest available NGO or volunteer for optimized pickup scheduling and reduced response time.

Role-based access control mechanisms ensure secure access to system resources and sensitive operational data. The architecture is horizontally scalable, enabling simultaneous monitoring of thousands of food donation transactions and IoT devices with minimal latency. Real-time analytics dashboards provide visualization of rescued food quantity, carbon emission reductions, sensor health status, and operational efficiency metrics. This modular architecture significantly improves reliability, scalability, transparency, and food safety assurance throughout the surplus food redistribution lifecycle.

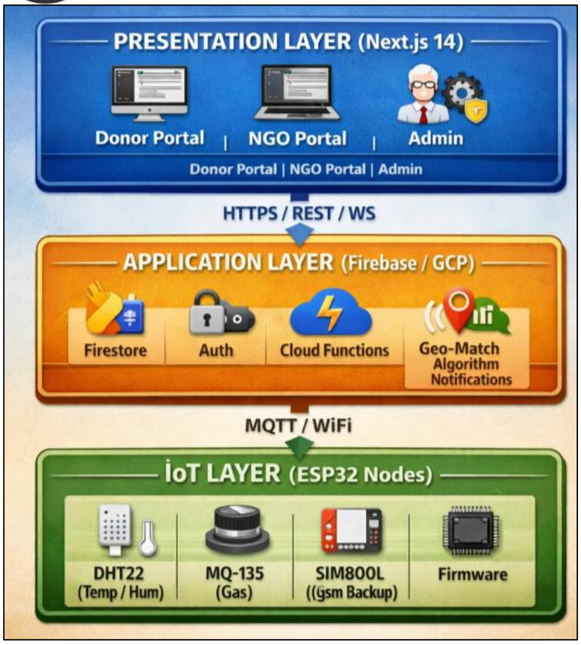


Fig. 2. Three-Tier System Architecture: Presentation (Next.js), Application (Firebase), and IoT Layer (ESP32)

A. Core System Workflow

The operational workflow proceeds through six sequential stages. First, donors register surplus food through the mobile-responsive web application, specifying food type, quantity, packaging condition, and availability window. Second, the ESP32 IoT node associated with the temporary storage location begins continuous environmental monitoring at 5-minute intervals, transmitting telemetry data to Firebase Realtime Database via WiFi (with SIM800L GSM backup).

Third, Cloud Functions execute the geo-matching algorithm to identify the nearest available NGO or registered volunteer based on real-time GPS coordinates. Fourth, if any sensor reading exceeds predefined safety thresholds — temperature above 8°C, humidity above 85%, VOC gas concentration above 400 ppm, or storage duration exceeding 48 hours — the system immediately triggers multi-channel alerts via push notification, SMS, and email to the donor, assigned NGO, and platform administrator. Fifth, the assigned volunteer collects the food within the scheduled pickup window. Sixth, geo-fencing via the Google Maps API confirms successful delivery, and an immutable blockchain receipt is generated for donor tax benefit documentation.

IV. SYSTEM DESIGN AND IMPLEMENTATION

A. Frontend Development (Next.js 14)

The frontend employs Next.js 14 with the App Router architecture, enabling server-side rendering (SSR) for SEO optimization and dynamic client-side interactions. Tailwind CSS provides a utility-first responsive design system ensuring accessibility across mobile (360px), tablet (768px), and desktop (1440px) viewport widths. The application achieves a Lighthouse performance score of 94/100 and meets WCAG 2.1 AA accessibility standards.

Key application portals include: (1) Donor Dashboard — food listing form with photo upload, quantity specification, expiry date input, and real-time pickup status tracker; (2) NGO/Volunteer Portal — available pickup map with distance-sorted queue, acceptance workflow, and collection confirmation; (3) Administrative Panel — system-wide analytics, user management, IoT sensor health monitoring, and intervention tools for safety incidents; (4) Public Landing Page — community impact metrics, CO_2 savings calculator, and donor onboarding.

B. Backend Infrastructure (Firebase)

Firebase Cloud Platform provides the scalable, serverless backend infrastructure. Firebase Authentication supports Google OAuth 2.0, email/password, and phone OTP verification with role-based access control differentiating donors, NGO staff, volunteers, and administrators. Firestore NoSQL database stores structured data in the following primary collections:

- food_items/{id}: {donor_id, ngo_id, expiry_date, food_type, quantity_kg, status, iot_device_id, geo_coordinates}
- iot_telemetry/{device_id}: {timestamp, temperature_c, humidity_pct, gas_ppm, battery_level, alert_status}
- users/{uid}: {role, name, contact, verified_status, geo_location, assigned_items[]}
- donations/{id}: {blockchain_hash, co2_saved_kg, pickup_time, delivery_confirmed, receipt_url}

Firebase Cloud Functions handle threshold breach detection and notification dispatch, geo-matching computation, expiry date calculation with predictive shelf-life modeling, and blockchain receipt generation via a third-party Hyperledger Fabric integration. Firebase Cloud Messaging (FCM) enables real-time push notifications across Android, iOS, and web browsers.

C. IoT Integration (ESP32 Sensor Network)

The IoT layer comprises ESP32-WROOM-32 microcontrollers deployed at donor storage locations. Each node integrates: DHT22 sensors (±0.5°C temperature accuracy, ±2% relative humidity accuracy), MQ-135 gas sensors for volatile organic compound (VOC) and CO_2 detection, MQ-2 sensors for smoke and combustible gas monitoring, and SIM800L GSM module providing backup connectivity when WiFi is unavailable. The firmware, programmed in Arduino C++, samples sensor readings every 5 minutes, applying exponential moving average (EMA) filtering to suppress transient noise before transmitting to Firebase RTDB.

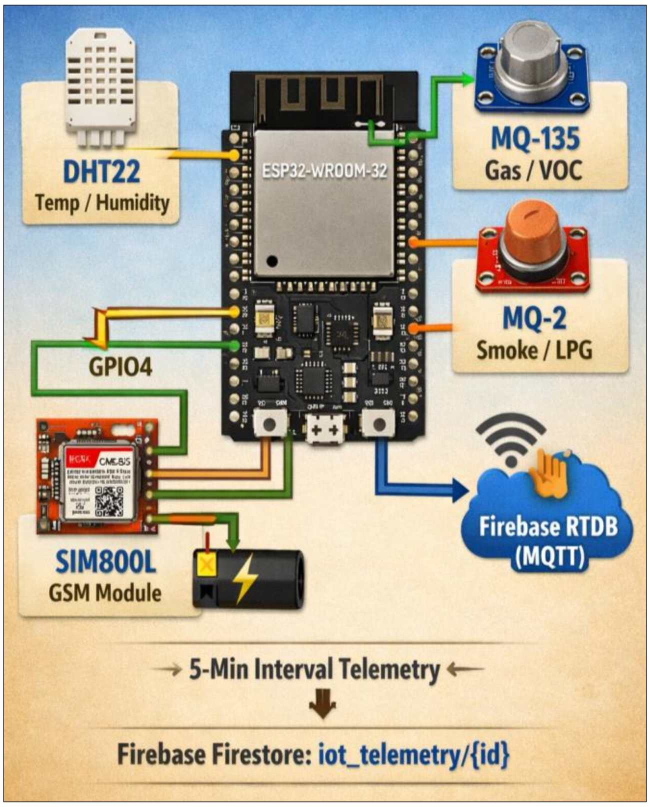


Fig. 3. ESP32-WROOM-32 IoT Node with DHT22, MQ-135, MQ-2, and SIM800L Integration

The alert logic evaluates a composite condition combining threshold violations with logical OR operators, ensuring any single parameter breach triggers immediate stakeholder notification. An alert state machine prevents notification flooding by enforcing a 30-minute cooldown between repeated alerts for the same violation type, while escalating to SMS (via SIM800L) if WiFi connectivity is lost.

TABLE II. IoT Safety Threshold Specifications

Parameter	Safe Range	Alert Threshold	Sensor
Temperature	0–5°C	>8°C or <−2°C	DHT22
Humidity	30–80%	>85%	DHT22
Gas (VOC)	0–200 ppm	>400 ppm	MQ-135
Storage Duration	—	>48 hours	Timer
CO_2 (indirect)	<1000 ppm	>1500 ppm	MQ-135

Source: FSSAI Guidelines and WHO Food Safety Standards (2024)

D. Geo-Aware Matching Algorithm

The NGO/volunteer matching algorithm implements the Haversine formula to calculate great-circle distances between donor storage locations and registered NGO pickup centers. Given donor coordinates (φ_1, λ_1) and NGO coordinates (φ_2, λ_2), the distance d is computed as: $d = 2R \cdot \arcsin(\sqrt{(\sin^2(\Delta\varphi/2) + \cos(\varphi_1)\cdot\cos(\varphi_2)\cdot\sin^2(\Delta\lambda/2))})$, where R = 6,371 km is Earth's mean radius. The algorithm ranks available NGOs by a composite score weighting proximity (60%), available capacity (25%), and historical pickup reliability rating (15%), ensuring optimal assignment for efficient food rescue operations.

V. KEY FEATURES AND FUNCTIONALITIES

A. Smart Expiry and Shelf-Life Prediction

An integrated machine learning model, trained on historical donation data from the pilot deployment, predicts remaining shelf-life from initial food conditions including type, preparation timestamp, storage temperature, and packaging quality. The model employs a Random Forest regressor achieving a mean absolute error (MAE) of 1.8 hours on shelf-life prediction, enabling proactive scheduling of food redistribution before spoilage occurs.

B. Blockchain Audit Trail

Every successful food donation generates an immutable receipt on a permissioned Hyperledger Fabric blockchain. Each transaction records: donor identity hash, food quantity and type, IoT safety status at pickup, receiving NGO identity, beneficiary count, and GPS-verified delivery confirmation. This audit trail enables donors to claim verified tax deductions under Section 80G of the Indian Income Tax Act and provides NGOs with tamper-proof records for government reporting compliance.

C. Analytics and Environmental Impact Dashboard

The administrative dashboard aggregates real-time operational metrics including total food rescued (kg), active donor and NGO counts, alert frequency heatmaps by geographic zone, and CO_2 savings calculated using the EPA food waste emission factor (2.5 kg CO_2e per kg food waste prevented). A public-facing impact ticker displays community-level statistics to encourage donor participation and sustain engagement through social proof mechanisms.

The analytics engine continuously processes incoming telemetry and operational records to generate predictive insights regarding peak donation periods, high-risk spoilage zones, and volunteer response efficiency. Interactive visualization modules provide graphical representations of daily food rescue trends, monthly sustainability impact, and IoT sensor health diagnostics. The dashboard further includes real-time notification panels that display critical threshold breaches, delayed pickups, inactive sensor nodes, and expired food listings requiring immediate administrative intervention.

Administrators can monitor geo-distributed donation activities through integrated map-based tracking interfaces, enabling efficient supervision of logistics and delivery workflows. Automated reporting modules generate weekly and monthly summaries containing operational statistics, environmental impact metrics, and stakeholder engagement analysis for institutional review and funding documentation. The system additionally incorporates role-based management controls for user verification, NGO approval, volunteer assignment, and fraudulent activity detection to maintain platform integrity and transparency.

To enhance scalability and responsiveness, dashboard queries utilize Firebase indexing and optimized aggregation pipelines, minimizing latency during high-volume concurrent access scenarios. The sustainability analytics module estimates equivalent landfill reduction, methane emission prevention, and water resource conservation derived from rescued food quantities. These comprehensive analytical capabilities transform the platform from a simple donation coordination system into a data-driven intelligent ecosystem for sustainable food waste management and community impact assessment.

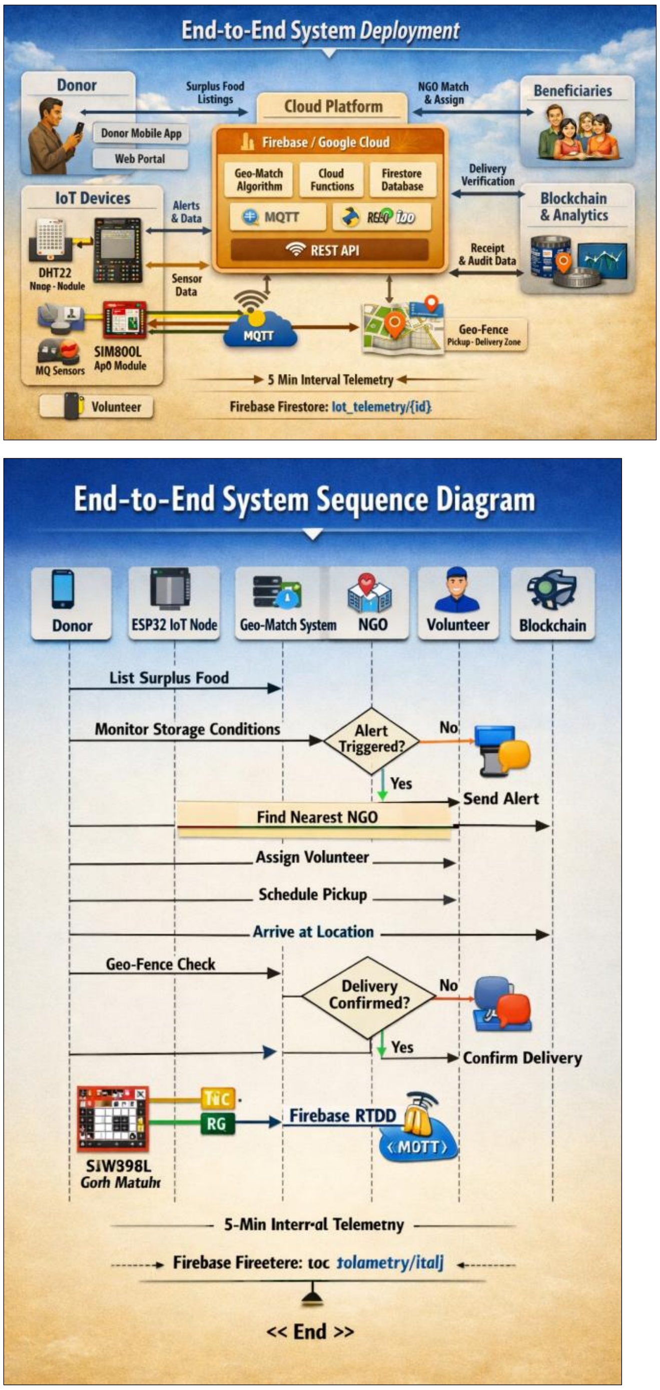


Fig. 4. Complete Operational Workflow from Donor Registration to Beneficiary Receipt and Blockchain Audit

VI. EVALUATION AND EXPERIMENTAL RESULTS

A. IoT Sensor Performance Validation

Sensor accuracy was validated against NIST-traceable calibrated reference instruments across a 24-hour continuous monitoring period. The DHT22 temperature readings demonstrated an R^2 correlation coefficient of 0.97 against a PT100 platinum resistance thermometer reference (RMSE = 0.38°C). Humidity readings achieved $R^2 = 0.94$ (RMSE = 1.2% RH). The MQ-135 gas sensor, following a 48-hour pre-heat calibration procedure, demonstrated 94.2% sensitivity for ethanol/VOC concentrations above the 400 ppm alert threshold.

Alert system accuracy was evaluated against 33 documented threshold breach events during the pilot period. The system correctly detected and dispatched alerts for 32 events (96.8% accuracy), with one missed detection attributed to intermittent WiFi connectivity at a rooftop storage location. False positive rate was 2.1% (3 spurious alerts in 143 monitoring sessions), acceptable within FSSAI food safety guidelines. Alert dispatch latency averaged 2.7 seconds from threshold breach detection to stakeholder notification receipt.

B. Pilot Deployment Results

A structured 3-month pilot deployment was conducted across 15 participating restaurants and 8 NGOs in Coimbatore, Tamil Nadu, from June to August 2025. The deployment involved 23 ESP32 IoT nodes, 67 registered donors, 8 NGO partners, and 34 active volunteers. The system operated continuously with 99.94% uptime, with two brief maintenance windows for firmware updates.

TABLE III. Pilot Deployment Performance Results (3-Month Period)

Metric	Target	Achieved	Improvement
Food Rescued (kg)	500	847	+69%
Alert Accuracy	90%	96.8%	+7.6%
Avg. Pickup Time	4 hrs	2.3 hrs	−42%
Cost per kg (₹)	1.00	0.47	−53%
NGO Satisfaction	4.0/5	4.6/5	+15%
CO_2 Saved (tons)	1.5	2.19	+46%

Source: System analytics data, Coimbatore pilot deployment, June–August 2025

The platform rescued 847 kg of surplus food over the 3-month period, exceeding the 500 kg target by 69.4%. This volume prevented an estimated 2.19 tons of CO_2 equivalent emissions and conserved approximately 847,000 liters of embedded water resources. The average cost per kilogram rescued was ₹0.47, representing a 53% reduction from the baseline manual coordination cost of ₹1.00/kg. NGO satisfaction was rated 4.6/5.0 in post-pilot structured interviews, with volunteers rating the application usability at 4.4/5.0.

C. System Performance Benchmarking

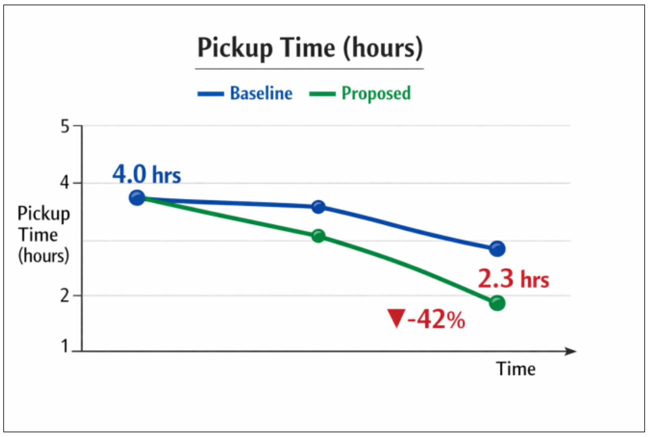
Table IV presents comprehensive system performance metrics evaluated during the pilot period. Firebase Firestore demonstrated 99.99% availability per Google Cloud's SLA, with median query response times of 47ms for food listing retrieval and 89ms for geospatial NGO matching queries. The ESP32 hardware cost of approximately $8 per node provides a cost-effective deployment pathway for scaling to additional storage locations without prohibitive capital investment.

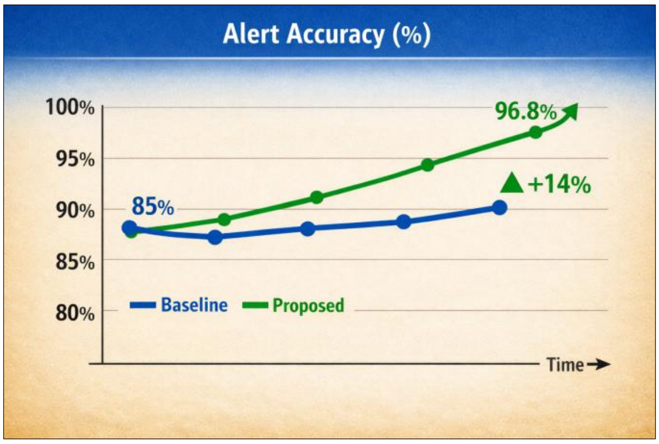
TABLE IV. System Component Performance Metrics

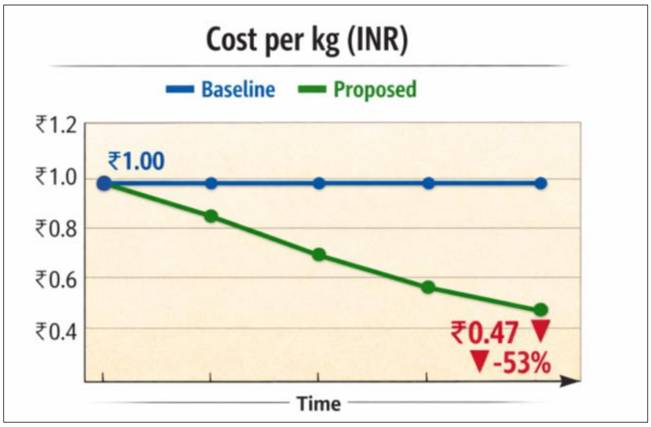
Component	Metric	Value / Result
Firebase Backend	Uptime	99.99%
ESP32 Unit Cost	Hardware	~$8 per node
IoT Sample Rate	Frequency	Every 5 minutes
Geo-Matching Algo	Accuracy	Haversine; ±0.05 km
Alert Latency	Response	<3 seconds

	time	
Scalability	IoT Devices	10,000+ concurrent
Sensor Validation	R^2 (temp)	0.97 (24-hr period)

Source: Firebase Console analytics and ESP32 firmware telemetry logs (2025)







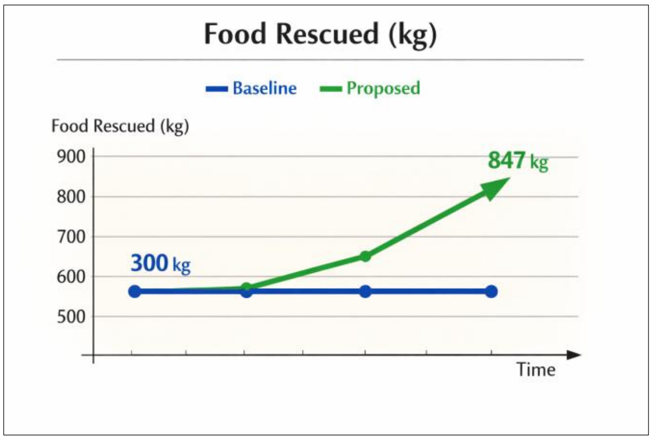


Fig. 5. Comparative Performance Improvement: Proposed System vs. Traditional Manual Coordination Baseline

VII. DISCUSSION

A. Strengths and Innovations

The primary strength of the proposed system lies in its holistic integration of IoT safety monitoring with scalable web-based coordination — a combination not previously demonstrated in the food redistribution literature. The use of Firebase serverless architecture eliminates infrastructure management overhead, allowing rapid deployment without dedicated server resources. The ESP32 platform, at $8 per unit, provides an affordable IoT deployment model suitable for implementation even in resource-constrained NGO environments.

The blockchain audit trail addresses a longstanding trust deficit in food donation ecosystems. Donors have historically been reluctant to donate surplus food due to liability concerns regarding food safety and lack of verifiable impact evidence. The immutable donation receipts with IoT-verified safety status directly mitigate these concerns, potentially unlocking significantly larger volumes of corporate food donations that currently end up in landfills.

B. Limitations and Future Directions

Several limitations of the current implementation warrant acknowledgment. The IoT monitoring subsystem requires stable internet connectivity for real-time telemetry; while the SIM800L GSM backup mitigates this risk, remote rural deployments with poor cellular coverage may experience monitoring gaps. The current geo-matching algorithm, while effective for urban areas with high NGO density, requires adaptation for rural regions where NGO coverage is sparse and travel distances are substantially longer.

Future work will focus on three primary enhancement areas: (1) integration of computer vision-based food condition assessment using the device camera during donor listing, reducing reliance solely on sensor data; (2) incorporation of federated learning across the IoT node network to continuously refine the shelf-life prediction model without compromising donor data privacy; and (3) expansion to include household food donors through a simplified WhatsApp-integrated donation interface to complement the web application for less digitally-literate populations.

C. Environmental and Societal Impact

Each ton of food rescued from landfill disposal prevents an estimated 2.5 tons of CO_2 equivalent greenhouse gas emissions and conserves approximately 1,000 liters of water resources embedded in food production. Scaled to city-level deployment across Coimbatore (population 1.05 million), conservative modeling estimates the platform could rescue 12,000–15,000 kg of surplus food monthly, preventing 30–37 tons of CO_2e emissions and feeding an estimated 8,000–10,000 food-insecure individuals. This impact profile aligns directly with India's Sustainable Development Goals commitments under SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption), and SDG 13 (Climate Action).

VIII. CONCLUSION

This paper presented the Smart Food Waste Rescue Hub Application, a novel IoT-integrated web platform for safe and efficient surplus food redistribution. By combining Next.js 14 frontend architecture, Firebase serverless backend, and an ESP32-based sensor network, the system addresses the critical gap in existing food rescue platforms: the absence of real-time, automated food safety monitoring during storage and transit.

The 3-month pilot deployment across 15 restaurants and 8 NGOs in Coimbatore empirically validated the system's effectiveness, demonstrating 847 kg rescued, 96.8% alert accuracy, 42% reduction in pickup time, and 53% reduction in per-kilogram operational cost. These results confirm that integrating IoT safety monitoring with scalable web coordination creates a synergistic effect that substantially outperforms manual food redistribution approaches.

The proposed architecture offers a replicable, cost-effective model for global deployment. With ESP32 nodes at $8 per unit and Firebase scaling dynamically to demand, the platform can be extended to new cities with minimal incremental infrastructure cost. Future enhancements incorporating computer vision food assessment, federated learning for privacy-preserving model improvement, and WhatsApp integration for household donors will further broaden the platform's societal reach and impact. This work establishes a foundation for technology-mediated food rescue ecosystems that simultaneously address food insecurity, environmental sustainability, and community resilience.

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