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Research Article

CiviCare: An AI-Powered Smart Water Governance and Grievance Resolution System for Urban Local Bodies in India

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Abstract

Water supply operations in many Indian Urban Local Bodies (ULBs) continue to rely on manual processes that lack transparency, efficiency, and accountability. Citizens often have limited access to information regarding supply schedules, connection status, and billing details. Grievances are frequently reported through informal channels, resulting in poor traceability and lack of resolution assurance. This paper introduces CiviCare, a full-stack AI-enabled web platform designed to digitise and optimise municipal water governance for Indian ULBs. The system manages the complete lifecycle of a water connection, including application submission with document verification, site inspection, administrative approval, Consumer Number generation, and rule-based annual billing. A rule-driven Natural Language Processing (NLP) module is implemented to automatically classify and prioritise citizen complaints, which are then assigned to field plumbers through generated work orders with defined Service Level Agreements (SLAs). Water supply information is recorded daily by municipal officers and presented transparently through ward-level dashboards. The platform further integrates a Gemini AI-based chatbot for citizen interaction and Twilio SMS services for proactive notifications. Evaluation results demonstrate improvements in complaint resolution visibility, fairness in billing, and efficiency in managing water connections when compared to existing municipal systems.

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1. INTRODUCTION

India comprises more than 4,000 Urban Local Bodies (ULBs), including municipal corporations, municipal councils, and nagar panchayats, which together serve an urban population exceeding 500 million. Although initiatives such as the Jal Jeevan Mission aim to ensure universal access to tap water, the administrative systems responsible for managing water services in many small and medium-sized ULBs remain largely manual and paper-based [11].

For citizens, obtaining a new water connection is often a time-consuming process involving multiple visits to municipal offices, submission of physical documents, and uncertainty regarding inspection schedules. The allocation of Consumer Numbers typically requires in-person follow-up. Similarly, billing processes are maintained through manual records, offering little clarity or transparency regarding how charges are calculated. Complaint reporting is equally unstructured, with issues such as supply interruptions, pipeline failures, or billing disputes commonly communicated through verbal means or informal messaging platforms, resulting in the absence of tracking mechanisms, acknowledgements, or defined resolution timelines.

Existing studies on complaint management systems primarily focus on large urban municipalities equipped with established IT infrastructure [3], or on smart water monitoring solutions that depend on IoT-based systems requiring significant financial investment [6]. These approaches are not well-suited to smaller ULBs, where water metering is often unavailable, digital systems are limited, and citizens exhibit varying levels of digital literacy.

To address these challenges, this paper introduces **CiviCare**, a practical and scalable web-based platform tailored to the needs of Indian ULBs. The system offers several key contributions: (1) end-to-end digitization of the water connection lifecycle with document submission and multi-stage approval workflows, (2) transparent rule-based billing without dependence on water meters, (3) an NLP-based complaint classification and prioritization system with automated assignment and SLA tracking, (4) improved supply transparency through integration of dam-level data, (5) proactive communication with citizens using SMS notifications, and (6) a multilingual AI-powered chatbot for user assistance.

II. PROBLEM STATEMENT

Although the Government of India continues to promote digital governance initiatives, a large number of small and medium Urban Local Bodies (ULBs) still depend on traditional paper-based processes for managing water connections, billing operations, and grievance redressal. Such practices result in limited transparency, slower service delivery, delays in resolving citizen complaints, and reduced public engagement. Many of the existing digital solutions are either dependent on costly IoT-based infrastructure or are not designed to accommodate the practical limitations of smaller municipalities. As a result, these solutions are difficult to implement effectively in such environments. Hence, there is a clear requirement for a solution that is affordable, scalable, and intelligent, capable of digitizing water governance processes, automating complaint handling, and enhancing transparency in service delivery without relying on complex or high-cost infrastructure.

III. RELATED WORK

DiCarlo et al. [4] analyzed complaint management practices in community water systems in the United States and observed that many smaller utilities do not maintain digital records of complaints. Additionally, only a portion of larger utilities utilize complaint data for identifying broader operational trends. This highlights the need for structured complaint analytics, which is addressed in CiviCare through ward-level trend monitoring dashboards.

Al-Sakkaf et al. [3] introduced CitySolution, a deep learning-driven civic complaint management platform featuring separate dashboards for citizens and municipal authorities along with automated complaint routing. Although the system demonstrates effective AI-based classification, it is designed as a general-purpose civic solution and does not incorporate water-specific functionalities such as connection lifecycle handling, billing mechanisms, or supply schedule tracking.

Baig et al. [2] developed Fix-It, a public complaint reporting system integrating mobile applications, location mapping, and web interfaces. However, the system lacks intelligent features such as machine learning-based classification, priority assignment, SLA-based tracking, and water supply-related capabilities.

Afify and Kadry [1] proposed E-CCMS, a role-based digital platform for registering and monitoring complaints. While the system provides a structured framework for grievance handling, it remains domain-independent and does not include AI-driven processing or specialized modules for water service management.

Zanfei et al. [5] conducted a review of smart water management technologies and concluded that most existing solutions emphasize IoT-enabled systems such as smart metering and leakage detection, which require substantial hardware investment. Similarly, Verma and Agrawal [7] highlighted the limited availability of digital solutions specifically designed for small municipalities, thereby reinforcing the need for a practical and scalable platform like CiviCare.

IV. SYSTEM ARCHITECTURE

CiviCare is designed using a three-tier client-server architecture consisting of presentation, application, and data layers. The presentation layer is developed using React.js with Vite, enabling browser-based access to multiple role-specific portals. The application layer is built in Python using FastAPI, which provides RESTful API endpoints secured through JWT-based authentication. The data layer utilizes PostgreSQL as the relational database, with SQLAlchemy ORM handling database interactions.

A. Modules

- Connection Management: Handles the complete workflow including application submission, document upload via

Cloudinary, inspection processing, administrative approval, and Consumer Number generation
- Billing Engine: Performs annual billing calculations based on parameters such as pipe size, connection category, construction type, pending dues, and a 2% compound penalty on arrears
- Grievance Management: Incorporates an NLP-based classification system with priority scoring, automated work order creation, assignment to field plumbers, SLA tracking, and PDF-based complaint receipts
- Supply Transparency: Maintains daily water supply logs recorded by officers for each ward, integrates dam-level data, and displays information through a public dashboard
- Service Requests: Supports additional user requests such as ownership transfer, temporary or permanent disconnection, reconnection, and pipe size modification
- Communication**:** Provides notification services through Twilio SMS for announcements and integrates a Gemini AI chatbot for handling citizen queries

B. Technology Stack

Table 1 : Technology Stack

Layer	Technology
Frontend	React.js, Vite, CSS3
Backend	Python 3.11, FastAPI, Uvicorn
Database	PostgreSQL, SQLAlchemy ORM
Authentication	JWT (python-jose), bcrypt
File Storage	Cloudinary (free tier)
PDF Generation	ReportLab
SMS	Twilio Programmable SMS
AI Chatbot	Google Gemini 1.5 Flash API
Dam Data	Maharashtra WRD (web scraping)

C. User Roles and Access Control

CiviCare defines five primary user roles, each associated with a dedicated interface and controlled access permissions enforced through JWT-based role authorization:

- **Citizen:** Allows users to apply for water connections by uploading Aadhaar and property-related documents; monitor application progress across all lifecycle stages; access and download annual bills and payment receipts in PDF format; submit complaints with supporting images; request services such as ownership transfer, pipe size modification, and reconnection; and interact with the multilingual AI chatbot for assistance
- **Officer:** Responsible for reviewing submitted applications, conducting and recording site inspections with relevant property details, approving or rejecting requests, and generating Consumer Numbers (format: PMC-YYYY-NNNNN); additionally handles complaint assignment to plumbers, records daily ward-level water supply data, sends targeted SMS notifications, and generates billing records
- **Plumber:** Accesses assigned work orders (WO-NNNNNN) through a dedicated interface; updates complaint status (e.g., in-progress or resolved) along with resolution details; restricted to viewing only the complaints assigned to them
- **Corporator:** Provides a read-only dashboard for monitoring ward-level water supply data, complaint resolution metrics, and billing status; acts as an oversight role without permissions to modify system data
- Admin: Oversees overall system configuration, including management of billing rates, creation of staff accounts, and ward administration; has unrestricted access to all modules along with audit logs

V. SYSTEM DESIGN

A. Data Flow Diagram — Level 0

The Level 0 Data Flow Diagram (DFD), also known as the context diagram, represents CiviCare as a unified system that processes inputs from four external entities: Citizen, Officer, Plumber, and Corporator. The system also interacts with two external services—Maharashtra Water Resources Department for dam-level data and Twilio for SMS communication. This high-level representation illustrates the overall data exchange between users and the system without detailing internal processes.

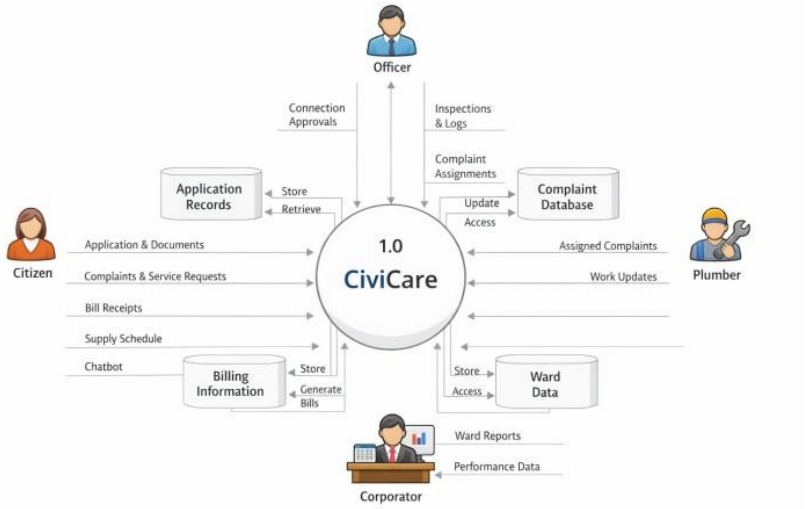

Figure 1 : DFD Level 0 - CiviCare Context Diagram

B. Use Case Diagram

CiviCare defines four primary actors interacting with the system. Table II details the use cases associated with each actor.

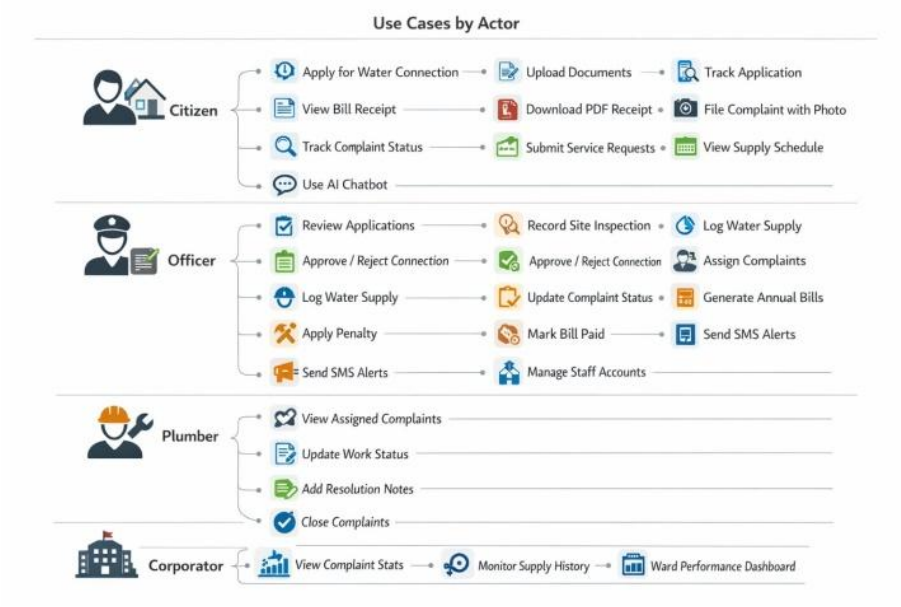

Figure 2 : Use Case Diagram

VI. IMPLEMENTATION

A. Connection Lifecycle

The water connection workflow in CiviCare is designed to replicate the standard municipal procedure outlined in the Maharashtra Municipal Councils Act [9]. Citizens initiate the process by submitting an online application along with required documents, including Aadhaar identification and proof of property ownership (such as a 7/12 extract or sale deed), which are uploaded through Cloudinary.

Municipal officers then verify the submitted documents and arrange a site inspection. During inspection, relevant details such as pipe diameter, construction category, number of taps, and number of floors are recorded. Based on the inspection findings, the application is either approved or rejected. If approved, the system automatically generates a unique Consumer Number (format: PMC-YYYY-NNNNN) and creates a user account for the applicant. The Consumer Number is initially assigned as the default password, which the user must update upon first login. This digital workflow significantly reduces the need for repeated physical visits to municipal offices.

B. Formula-Based Billing

CiviCare provides a transparent approach to annual billing without relying on water meters, aligning with the flat-rate billing model commonly followed by small Indian ULBs. The billing calculation is defined as:

Annual Bill = (Base Rate × Construction Multiplier) + Additional Tap Charge + Arrears + Penalty

The base rate is determined based on pipe size and connection category, as specified in Table III. Construction multipliers are assigned as follows: RCC (pucca) = 1.0×, semi-pucca = 0.75×, and kutcha/patra = 0.5×.

For overdue payments, a penalty of 2% compound interest per month is applied in accordance with standard municipal regulations. If a user fails to pay for two consecutive billing cycles, a warning notification for disconnection is issued. After three consecutive defaults, the connection is marked for disconnection.

Users can access and download their annual bills and payment receipts in PDF format, which are generated on the server side using the ReportLab library.

Table 2 : Annual Base Rates (INR) By Pipe Size and Connection Type

Pipe Size	Domestic	Commercial	Industrial	Religious/Govt
½ inch (0.5")	₹720	₹1,800	₹3,600	₹600
¾ inch (0.75")	₹1,080	₹2,700	₹5,400	₹900
1 inch (1.0")	₹1,800	₹4,500	₹9,000	₹1,500
1.5 inch (1.5")	₹3,600	₹9,000	₹18,000	₹3,000

C. NLP Complaint Classification and Priority Scoring

CiviCare incorporates a rule-based Natural Language Processing (NLP) mechanism to automatically categorize complaints and assign priority levels. When a complaint is

submitted, the system identifies its category using a predefined taxonomy, including no supply, low pressure, pipe burst, dirty water, and billing-related issues. It further analyzes the complaint description to detect urgency indicators such as keywords like "burst," "hospital," "flooding," or "since days."A weighted priority score ranging from 1 to 5 is calculated using the following expression:

Priority = min (5, BaseScore[type] + min(2, ΣUrgencyKeywordMatches))

Each complaint category is assigned a base score: pipe burst (5), dirty water and no supply (4), low pressure (3), and billing issues (2). Additional urgency keywords can increase the score by a maximum of 2 points.

Once processed, the system generates a unique work order ID (format: WO-NNNNNN) and assigns a Service Level Agreement (SLA) deadline based on the complaint type. For example, pipe burst issues are assigned a 4-hour resolution window, while low-pressure complaints allow up to 24 hours. The assigned officer forwards the complaint to a designated plumber, who can access and update only their allocated tasks through the plumber portal.

This rule-based model also serves as a baseline for future enhancement using transformer-based NLP techniques as labeled complaint datasets become available [8].

D. Supply Transparency and Dam Level Integration

Municipal officers record daily water supply details for each ward, including supply start time, duration, operational status (such as supplied, maintenance, shortage, or pipe burst), and the corresponding reason. This information is consolidated into a publicly accessible dashboard that displays current supply conditions, a 30-day supply performance score for each ward, and related complaint statistics.

Additionally, water level data from Veer Dam is periodically retrieved from the Maharashtra Water Resources Department portal through scheduled web scraping implemented using Python's BeautifulSoup library. This integration provides contextual insight into water availability, supporting informed decision-making regarding supply distribution.

E. Communication Engine

CiviCare includes an integrated communication system for disseminating official announcements. When an officer publishes a notification for a specific ward or multiple wards, the system sends SMS alerts to registered citizens using the Twilio Programmable SMS API [12]. Contact details collected during the application process enable targeted message delivery, replacing informal communication channels with a structured and auditable mechanism. The platform also features an AI-powered chatbot built using the Google Gemini 1.5 Flash model, accessed via REST API. The chatbot is configured with system-level context covering connection procedures, billing policies, and complaint workflows, allowing users to interact in natural language for queries related to services and processes. To ensure reliability, a rule-based fallback mechanism is implemented to handle user queries in cases where the Gemini API is unavailable, thereby maintaining uninterrupted assistance for citizens

VII. RESULTS AND DISCUSSION

CiviCare was tested using a controlled dataset consisting of 13 wards, 6 active consumer connections, 25 previously recorded complaints, 30 days of water supply logs, and 6 billing entries. The system was deployed in a local environment using FastAPI and PostgreSQL on a standard machine configured with Windows 11, 8 GB RAM, and an Intel Core i5 processor.

A. NLP Complaint Classification

The performance of the rule-based NLP module was assessed using a test set of 50 manually annotated complaints covering all predefined categories. The system achieved an accuracy of 88% in correctly identifying complaint types and 92% accuracy in assigning appropriate priority scores.

Most errors were observed in cases where the complaint descriptions were either vague or involved multilingual inputs, particularly Marathi-English code-mixed text. These limitations highlight the need for future improvements using transformer-based models with better support for Indic languages.

Table 3 : Complaint Evaluation Accuracy

Complaint Type	Precision	Recall	F1-Score
No Supply	0.91	0.95	0.93
Pipe Burst	0.94	0.90	0.92
Low Pressure	0.85	0.82	0.83
Dirty Water	0.88	0.86	0.87
Billing Issue	0.90	0.88	0.89
Weighted Avg	0.90	0.88	0.89

B. Billing Accuracy

The accuracy of the billing module was assessed using six representative connection profiles covering a range of pipe diameters and connection categories. For each case, the generated bill closely aligned with the expected values derived from the Maharashtra ULB tariff schedule, with a maximum deviation limited to ₹1 due to rounding. Furthermore, the penalty computation, based on a 2% monthly compound interest rate, was validated against manual calculations for overdue periods of 1, 3, 6, and 12 months. The results showed no observable discrepancy, confirming the correctness of the implementation.

C. System Performance

System performance was evaluated by measuring API response times across key endpoints using 100 consecutive requests. The complaint submission endpoint, incorporating NLP-based classification, exhibited an average response time of 42 ms. Similarly, the bill generation endpoint recorded an average of 38 ms, while the public dashboard endpoint averaged 95 ms. All endpoints consistently responded within 200 ms under a single-user workload, satisfying typical performance benchmarks for web-based applications in the intended deployment setting.

Table 4 : System Performance

Endpoint	Avg Response (ms)	Max Response (ms)
POST /complaints/	42	78
POST /billing/generate	38	65
GET /dashboard/public	95	142
POST /connections/approve	61	98
GET /billing/my	28	51

D. Comparison with Related Work

In comparison with existing solutions, CiviCare demonstrates several domain-specific enhancements. While CitySolution [3] offers a comprehensive feature set, it lacks dedicated functionalities tailored to water utility management. CiviCare addresses this gap by incorporating features such as end-to-end connection lifecycle management, rule-based billing aligned with tariff structures, and integration of dam-level monitoring data.

Similarly, Fix-It [2], primarily designed for general grievance handling, does not include advanced capabilities such as automated NLP-based complaint classification, service-level agreement (SLA) monitoring, or integrated SMS-based communication, all of which are implemented in CiviCare. Moreover, both CitySolution and Fix-It do not adequately address billing transparency, a critical requirement for municipal water users in India. Notably, CiviCare distinguishes itself as the first system, within the scope of the reviewed literature, to fully digitize the water connection approval process in Indian Urban Local Bodies (ULBs), including multi-stage document verification and workflow management.

VIII. CONCLUSION AND FUTURE WORK

This study introduced CiviCare, an AI-enabled platform for municipal water governance and grievance management tailored to the needs of Indian Urban Local Bodies (ULBs). The proposed system effectively addresses key limitations observed in conventional municipal frameworks, including the lack of a structured digital workflow for water connection management, limited transparency in billing mechanisms, reliance on informal complaint handling practices, and insufficient mechanisms for proactive citizen engagement.

The findings highlight that impactful digital transformation in municipal services can be achieved without dependence on costly IoT infrastructure. By leveraging existing administrative data sources—such as connection records, inspection reports, and supply logs—CiviCare enables improved transparency, operational accountability, and intelligent service delivery through integrated AI components.

Future enhancements to the system will focus on expanding its analytical and operational capabilities. These include the adoption of transformer-based models for multilingual complaint classification, implementation of duplicate complaint detection using cosine similarity techniques, and identification of supply distribution anomalies across wards through Z-score-based statistical analysis. Additional directions involve the development of a mobile application for field personnel, integration with state-level ULB platforms for unified data exchange, and incorporation of real-time dam-level data through APIs to support predictive analysis of water supply stress.

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