A COLLABORATIVE APPROACH TO ROAD INFRASTRUCTURE MONITORING USING ROADLENS

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The thesis titled "**A COLLABORATIVE APPROACH TO ROAD INFRASTRUCTURE MONITORING USING ROADLENS "** submitted by **BIPUL DEY**, **MD. TOWHIDUL ISLAM RIFAT**, session:2019-20, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of **BACHELOR OF URBAN AND REGIONAL PLANNING (BURP)** on **July1, 2025.**

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ABSTRACT

Monitoring urban road infrastructure effectively remains a challenge in the developing world. Conventional survey methodologies, although important, are generally infrequent, costly, and non-participatory, which is often the case for road monitoring surveys. This study details the development of RoadLens, an open-source, geo-spatial, collaborative platform, which combines public participatory data collection with spatial analysis, established for regularly monitoring distress on roads in real-time. The RoadLens project was implemented in Rajshahi City, Bangladesh, and incorporated a workflow for assessing contributor participation, mobile-friendly data collection, and visualization of the geo-spatial data in an interactive forum for multi-user engagement. A field survey with 20 members trained as RoadLens contributor assessors, identified 388 geo-located distress points that reported a number of attributes including the distress type and severity, drainage quality and consistency, traffic counts, and land-use adjacent to roadways covering 34.1% of road network within Rajshahi city. Spatial analytics and statistical analyses including Kernel Density Estimation, Hot Spot Analysis (Getis-ord Gi) and Chi-Square tests, raised awareness between infrastructure deterioration and being impacted by significantly urban environmental factors. RoadLens offers a mechanism not only for data-driven maintenance prioritization for municipalities, but also utilizes citizen engagement, transparency, and accountability to bring awareness to responsible authorities. RoadLens offers a collaborative monitoring framework that is scalable, cost-effective, and easily replicated for participatory urban infrastructure governance in future developing cities.

Keywords: *Participatory GIS, Crowdsourced Data, Spatial Analysis, Road Distress Mapping, Hot Spot Analysis, Open-source Web Application, Urban Infrastructure, Public Engagement, RoadLens, Infrastructure Prioritization, Smart Governance, Rajshahi City.*

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Glossary of Terminology

***Adjacent Area Type*:** The dominant land use type (e.g., residential, commercial, institutional) surrounding a road segment or distress point, used to assess environmental or functional impacts.

***Crowdsourcing*:** A participatory data collection method that relies on voluntary contributions from individuals (e.g., citizens, students) to report or validate information—in this case, road distress conditions.

***Distress Point*:** A location on a road surface where visible structural damage (e.g., potholes, cracks) has occurred, documented through field surveys or digital tools.

***Distress Severity*:** A classification of road damage intensity, typically divided into Low, Medium, or High, based on visual assessment and its impact on road usability or safety.

***Drainage Quality*:** A measure of how well a road segment manages surface water runoff. Classified as Good, Moderate, or Poor, it is a crucial factor influencing long-term pavement performance.

***Geotagging*:** The process of associating digital data (e.g., images) with geographic coordinates (latitude and longitude), often via mobile GPS during data collection.

***GIS (Geographic Information System)*:** A computer-based system for capturing, storing, analyzing, and visualizing spatial or geographic data.

***Kernel Density Estimation (KDE)*:** A spatial analysis technique that calculates the density of features in a defined area, helping to visualize clustering patterns.

***Open-ended Questionnaire*:** A qualitative data collection tool used to capture detailed feedback, perceptions, and suggestions from participants beyond multiple-choice options.

***Participatory Mapping*:** A collaborative method where individuals actively contribute geographic information, often using mobile devices, to represent real-world features or issues.

***Pavement Distress*:** Physical degradation of a road's surface layer due to traffic loads, environmental conditions, or material failure, including potholes, cracking, patching, and raveling.

***RoadLens**:* The digital web-based platform developed in this research to enable citizens to report road distress conditions and visualize them via GIS mapping tools.

***Spatial Analysis**:* The process of examining the locations, patterns, and relationships of geographic features to identify trends or inform decisions.

***Supabase**:* A cloud-based PostgreSQL database used in this project for managing authentication, storing distress data collected by structured survey and geospatial data in real time.

***Traffic Volume**:* An estimate of the number of vehicles using a particular road segment, categorized as Low, Medium, or High. Used to evaluate potential causes of surface deterioration.

***Web GIS**:* A web-based system that allows users to collect, manage, and visualize spatial data through interactive maps accessible from browsers or mobile devices.

Chapter 1:

Introduction

This chapter introduces the motivation and context of the study, focusing on the importance of effective road infrastructure monitoring in urban environments. It discusses the limitations of traditional survey methods and highlights the growing relevance of participatory and GIS-based approaches. The chapter also presents the aims and objectives of the research, the rationale behind developing the RoadLens platform.

1.1 Background of The Study

Urban infrastructure refers to the buildings and facilities which enable the physical and functional needs of cities, including transport, water supply, energy, waste disposal, and communications networks(Dalla Longa, 2023). Road infrastructure is one of the most fundamental of these, directly influencing mobility, safety, and economic activity. Roads are also often perceived as a measure of the health of the city, serving as a lifeline between people, services, and goods (Encyclopedia, 2025).

In developing countries such as Bangladesh, road maintenance always a perpetual challenge due to challenges due to factors such as inadequate planning, resource limitations, and poor inter-agency communication (Adewumi, 2022). These systemic issues often result in rapid road deterioration, rising maintenance costs, and a decline in public satisfaction with city governance and services.

Monitoring road infrastructure has seen considerable advancements in developed nations through technologies such as LiDAR, high-resolution satellite imagery, vehicle-mounted sensors, and automated inspection platforms (Ramesh, 2021). Nonetheless, these expensive methods are often impractical for adoption in countries like Bangladesh due to their economic conditions. As a result, low-cost participatory strategies that involve public engagement, such as data collection via mobile devices, become essential. The idea of including citizens—the so-called "stakeholders" of public infrastructure—in the monitoring process is increasingly being investigated as a sustainable solution in settings with limited resources (Hussain et al., 2021).

In today's digital era, surveillance of this infrastructure must evolve to include data-informed and inclusive mechanisms that account for both spatial contexts and community needs. Evidence shows that combining civic engagement and digital technologies—specifically mobile phones and GIS can offer an interactive, real-time way to monitor urban infrastructure(Ramesh, 2021; Harris et al., 2017). Citizens, as daily users of public roads, can contribute meaningful data when supported with simple interfaces and minimal training. (Brand, 2005). When processed and visualized using GIS, such crowdsourced data can enable targeted, data-driven decision-making for urban maintenance planning (S A Ojo *et al*., 2019).

1.2 Problem Statement

Road maintenance systems in developing countries use top-down approaches which depend on periodic manual inspections that frequently fail to identify the complete scope of infrastructure problems. Road maintenance prioritization becomes ineffective because of these problems which causes repair delays and worsens road conditions. This situation is worsened by the failure to include feedback from users who regularly experience road conditions in the evaluation process. (Pouliquen et al., 1988.).

Modern infrastructure monitoring requires a system based on public collaboration and spatial technology to enhance performance through transparent citizen involvement. To resolve these issues a framework must be inclusive and scalable while costing less that uses citizen reports combined with spatial analysis for collaborative road infrastructure management.

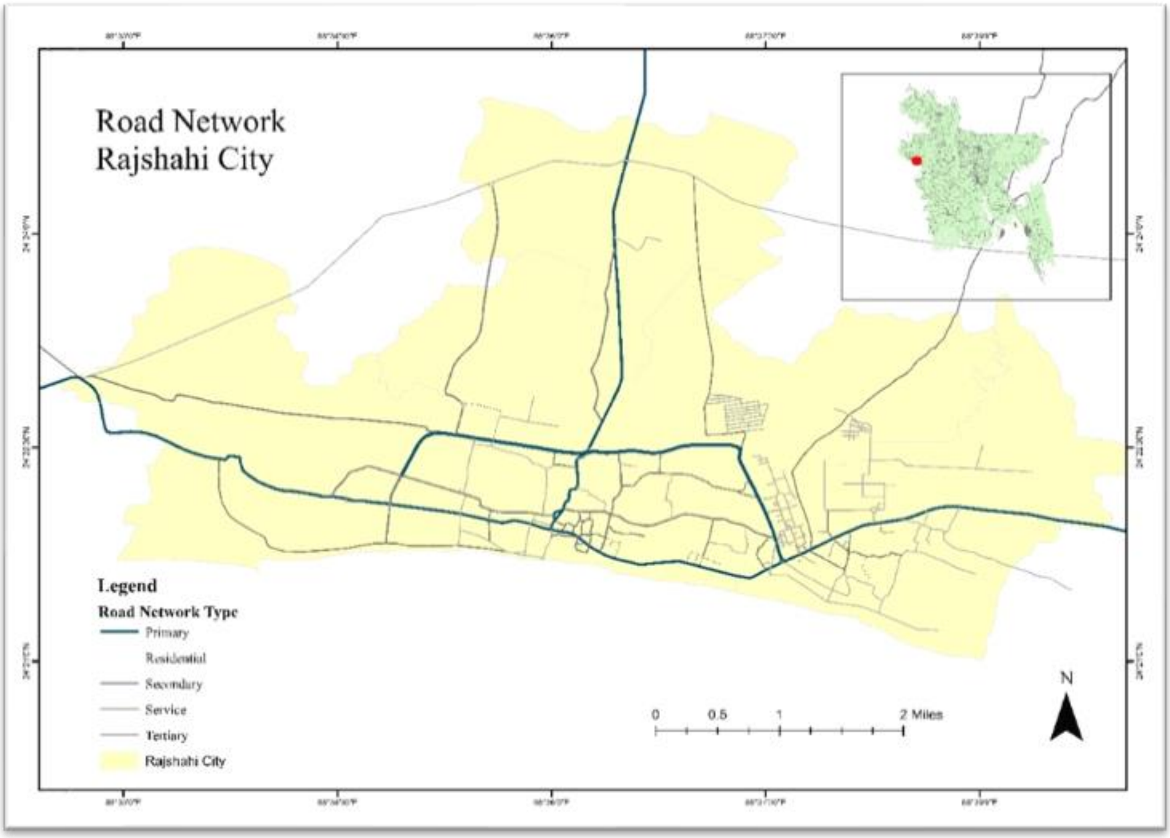
1.3 Rationale of the Study

Through its web-based GIS platform Road Lens the system collects and analyzes crowdsourced road distress points data for visualization. Through citizen involvement in monitoring and GIS data integration the platform creates an open accessible and budget-friendly system for urban road maintenance decisions based on data. The process is informed by new studies on public participation, including digital participation, and infrastructure management in developing contexts (Hussain et al., 2021; Douangphachanh & Oneyama, 2024).

1.4 Study Area

The study focuses on the northern part of Bangladesh, known as Rajshahi City, which has strategic importance due to its status as a city of education and culture. Rajshahi houses a number of universities, colleges, and research institutions, making its roads very vital in maintaining connectivity to keep the city functional. As an educational city, the transport network system is very important for the movement going smoothly among the students, faculties, and all the residents traveling in different zones of the city (Hasan et al., 2021).

RCC is the designated authority to manage a majority of road networks in this city. These roads link most vital infrastructural areas within the city. Assessment of these roads is, therefore, quite instrumental, especially due to some recent development initiatives on improving the transportation system in this city (Rahman & Hasnat, 2020).



Source: Authors' Preparation, 2025

Figure 1: Road Network Map; LGED,24

The study includes a road network map of Rajshahi City shown in figure 1 to provide a visual representation of the study area, showcasing the interconnectedness of its urban roadways. The research aims to assess road infrastructure distress and identify high-risk sections that require urgent maintenance to support the city's continued development as an educational and commercial hub.

1.5 Aim of the Study

The aim of this study is to create a public participation-based framework that uses a web-enabled GIS platform to support the monitoring, and evaluation of urban road infrastructure through collaborative data collection and spatial analysis.

1.6 Objectives

- To develop an open-source database and participatory GIS platform for collecting, visualizing, and analyzing road infrastructure data.
- To enable public participation in road condition reporting through a mobile-integrated survey system.
- To apply advanced spatial analysis techniques within the GIS framework to inform data-driven decision-making for road infrastructure monitoring, repair prioritization, and long-term planning.

1.7 Scope and Limitations

The study focuses on primary road segments within a selected urban area, where road condition data will be collected through public contributions using mobile and web-based tools. While the system is designed for real-time engagement, the accuracy of the collected data depends on user participation and the consistency of inputs. Furthermore, integration with official infrastructure systems may require institutional support beyond the scope of this study. However, through a structured contributor evaluation process and a real-time feedback loop, the framework aims to ensure data quality and scalability.

Chapter 2:

Literature Review

The chapter reviews academic work with practical applications which focus on road condition assessment together with crowdsourced infrastructure monitoring and spatial analysis methods. The chapter performs a critical assessment of worldwide methods by highlighting missing components in data gathering processes as well as limited stakeholder participation and delayed analysis. The study focuses on papers which integrate public involvement together with mobile GIS technology and road damage evaluation frameworks. The chapter uses literature review to build the theoretical base for RoadLens development while proving the study's importance for urban infrastructure planning in developing areas.

2.1 Conceptualizing Urban Infrastructure and Road Systems

The idea of urban infrastructure is based on the necessity for cities to operate efficiently while addressing challenges related to population growth, environmental sustainability, and the provision of public services. Urban infrastructure consists of a network of interconnected elements, including roads, drainage systems, water supply, electricity, public transportation, and digital communication networks (Quintero & Pierre, 2002). These systems not only facilitate daily life but also shape urban form, connectivity, and socio-economic development.

Among these, roads are arguably the most crucial types of infrastructure because of their diverse functions that facilitate human movement, economic operations, and emergency access. Road systems are essential for urban life, allowing the movement of goods, services, and individuals throughout neighborhoods and regions. The standard and accessibility of roads are indicative of the overall culture of governance and accountability in the public sector (Onuigbo & Orisakwe, 2013).

Road infrastructure maintains links with other systems which influence environmental conditions along with traffic flow and land use patterns. The metropolitan system experiences reduced economic performance together with worsened social disparities because of unmonitored and unmaintained road structures. The interconnected nature of road networks requires urban planners to view them as core components of the infrastructure system rather than individual separate elements. The persistent challenge stems from inadequate planning alongside both financial and human resource shortages and poor interagency collaboration (Adewumi, 2022). System inefficiencies lead to higher maintenance expenses over time while accelerating road degradation and diminishing public confidence in government services. Road conditions serve as a visible indicator through which residents can evaluate how well city government manages its infrastructure policies and performance. The majority of developing nations experience fast road deterioration because of inadequate maintenance practices and limited funding and uncoordinated institutional operations. The urban infrastructure requires special attention for roadways because they represent a crucial and vulnerable component which needs proper infrastructure monitoring.

2.2 Challenges in Urban Infrastructure Monitoring

The process of monitoring urban infrastructure faces multiple challenges because of technical difficulties and financial constraints and administrative barriers. Developing nations face critical difficulties in uniting infrastructure surveillance with repair activities because they lack budgetary support and face organizational fragmentation of public institutions (Adewumi, 2022). The local government faces challenges from political interference and bribery and excessive national government rules which result in poor project execution and delayed maintenance. The traditional infrastructure assessment methods which are costly and time-intensive fail to deliver sufficient information for present-day urban administration (Hasan et al., 2021). Municipalities cannot effectively identify their high-priority zones because they lack participatory monitoring systems that would enable this capability.

2.3 Road Condition Monitoring: Gaps and Limitations

Traditional methods such as manual surveys are time-consuming and are likely to produce outdated information. They are slow and fail to capture the entire situation of road conditions, especially under constrained budgetary situations (Government of Bangladesh Roads & Highways Dept., 2001). The limitations of current practices point towards cost-effective, scalable, and participatory models that integrate both manual and automated data collection methods (Ramesh, 2021; Chen et al., 2014).

2.4 Technological Approaches in Monitoring and Data Collection

With the increased availability of digital technologies, the monitoring of infrastructure has considerably evolved. Smart sensing technologies, cloud computing, and low-cost mobile applications now offer a feasible alternative to traditional field surveys. Mobile phones equipped with GPS, accelerometers, and cameras have emerged as a basic tool in infrastructure data collection, particularly in resource-poor environments (Douangphachanh & Oneyama, 2024; Ramesh, 2021). Cloud-based platforms provide constant and centralized data updating from contributors who are decentralized. Such platforms provide real-time data uploading, geotagging, and image-based reporting, thereby vastly increasing the scope and magnitude of data collection (Harris et al., 2017). Digital tools also have the ability to integrate very easily into open-source web applications, thereby making them user-friendly and affordable for both government institutions and public users. In the majority of pilot studies, such systems have been shown to achieve collecting accurate road condition data and enabling automatic road distress type classification based on machine learning approaches.

2.5 Visualization and Analysis Methods

GIS systems serve as the core tool for visualizing and analyzing spatial data related to infrastructure. These applications enable users to build condition-based road classifications and generate heatmaps together with clustering zones and distress maps (Ojo et al., 2019; Muthama et al., 2016). Interactive dashboards powered by GIS technology allow users to view current information and select road distress according to location points and types and severity levels (Obedin et al., 2019.; Scolamiero et al., 2025).

2.6 The Participatory Model and Mobile Integration

The present-day urban infrastructure management employs participatory monitoring as an innovative method especially for metropolitan zones which have restricted resources. The practice of involving ordinary citizens in collecting infrastructure data enables communities to establish power while keeping ownership and public asset stewardship open (Brand, 2005; Harris et al., 2017). The availability of smartphone applications together with online portals makes it easier for non-professionals to participate. The portals simplify data input by providing straightforward interfaces and step-by-step attribute selection which reduces technical complexity and demonstrates that mobile applications can successfully support citizens in reporting road defects (Ramesh, 2021; Douangphachanh & Oneyama, 2024)

Moreover, participatory systems facilitate consistent data collection and provide space-dispersed observations that an agency may otherwise miss. In their visualization with GIS platforms, citizen-collected data allow municipal governments to simplify high-effort area identification, track trends, and target interventions. They also create essential feedback loops—adding a glimpse into outcomes that ensures steady public contributions.

2.7 Addressing Inequities and Institutional Inclusion

Evidence also indicates that a number of considerations related to environmental and infrastructure justice must be taken into account in order to include highways in a surveillance system (Klauser & Albrechtslund, 2014). Underdeveloped areas are even more likely to be quarantined from emergent neglect (emergency interrogation and repair), by participatory measures on this level. Governments must also engage with participatory systems to be able to respond to crowd-sourced data. By building a feedback mechanism, and including municipal or local authorities to participate in the flow of information, it is easier to resolve grievances that are administratively obvious(Pouliquen et al., 1988; Obedin et al., 2019). Real-time GIS-based command and control overlays can also improve response times and repairs (Chen et al., 2014).

2.8 Integrating Citizen-Generated Data into Infrastructure Monitoring

One of the most persistent challenges faced by urban infrastructure management, particularly in municipal governments, is the problem of data fragmentation. Critical information about road infrastructure is often isolated across multiple departments—such as urban planning, public works, and finance—and stored in incompatible systems, thus forming institutional data silos (Du et al., 2023; FCM, 2022). This fragmentation diminishes strategic planning by making it impossible to have a holistic view of system-wide infrastructure assets and leads to inefficient resource prioritization. To break down these silos, modern integrated asset management approaches aim to unify siloed data streams in a single registry, integrating GIS, CMMS (computerized maintenance management systems), and financial data (Du et al., 2023; FCM, 2022). In this model, citizen-sourced data via could serve as an instrumental supplemental data source, as long as it is officially ingrained into the Government's workflow. Meeting interoperability frameworks, institutional support and data validation pipelines (OECD, 2025; UN-Stats, n.d.) are needed for that level of integration.

Case studies provide evidence. New York City's TreesCount! initiative has incorporated citizen-sourced information in urban forestry policy, while Denver's Denveright plan harnessed input from over 15,000 residents to inform infrastructure planning for the city (Cities of Service, n.d.; Crowdsourcing Week, 2025). The case studies demonstrate the potential of cohort platforms to contribute to data for infrastructure planning, budgeting, and decision-making, assuming municipalities enhance inclusive, technology-facilitated models.

2.9 Motivation and Gamification in Participatory GIS

The use of motivational strategies in participatory platforms is becoming commonplace. Participatory platforms can implement gamification elements like leaderboards, points and badges to help promote governing a task. A reminder, user behavior studies tell us to be careful when designing solely around extrinsic motivators as these types of motivating factors may not result in long-term engagement (Antoniou et al., 2025; Iacovides et al., 2018).

While using motivational strategies, ethical considerations must also be accounted for in a gamification context. Design that is too competitive can lead to adverse outcomes from users like getting overwhelmed, disengaging altogether or compromising data integrity (Kim & Werbach, 2017; Smartico, 2025). For RoadLens, the case studies shed light on related design improvements for future iterations, and they start to shape the basis of motivational frameworks that will influence and encourage, rather than exploit, participants.

2.10 Ensuring Data Quality

Maintaining data accuracy is a significant concern when data is crowdsourced from a wide range of contributors with varying technical abilities. The literature indicates that data quality is a multi-phased process that involves training, real-time monitoring, and post-submission checking (Wiggins et al., 2012; Bowser et al., 2021). Before data collection, contributors are able to take advantage of a structured onboarding process, which may include interactive tutorials or quizzes (components that are somewhat embedded in the RoadLens evaluator process). During collection, digital prompts, dropdowns, mandatory image capture, and duplicate reporting mechanisms ensure protocol compliance. After submission, datasets must undergo manual and automated reviews for statistical outliers, logical inconsistencies, and spatial errors (Biessmann et al., 2021; NumberAnalytics, 2025).

Effective projects such as Safetipin in India and OpenStreetMap for disaster response show how layered validation models can enhance citizen reporting reliability in low-resource settings (Al-Rousan & Khedaywi, 2022).

2.11 Advancing Spatial Analysis for Infrastructure Monitoring

RoadLens integrates spatial analysis to visualize and understand the distribution of infrastructure distress. While descriptive tools like Kernel Density Estimation (KDE) provide an initial overview of concentration areas, they lack statistical inferencing capabilities (Manepalli, 2011). As such, research recommends applying inferential spatial methods like Getis-Ord Gi* to identify statistically significant clusters of road distress (Hazaymeh & Alomari, 2022).

Furthermore, since roads operate along linear networks rather than open space, network-constrained analyses offer superior accuracy over Euclidean methods. Tools such as Network KDE and network Gi* have been demonstrated to better reflect infrastructure realities (Shahzad, 2020; ArcGIS Pro, n.d.). These analytical frameworks are essential in the thesis not only for identifying priority maintenance zones, but also for justifying decisions in budget allocation and planning—especially under constrained municipal resources.

2.12 Institutional Integration Considerations

The sociotechnical challenges around implementing participatory sensing platforms, in the Global South often include lack of digital access as a result of emitting digital exclusion, low level of trust to institution and bureaucracies, which tend to be organized in a way that is inflexible (Al-Rousan & Khedaywi, 2022). One example could be there were not many available smartphones or internet connectivity in Rajshahi to limit productive participations to only certain groups of people and thus limiting the needed dataset.

When it comes to exploiting communities of vulnerability where data has been extracted without benefiting the community locally in consideration of digital colonialism, equitable design is key (Al-Rousan & Khedaywi, 2022). RoadLens addresses this through locally trained data collectors; as well as, transparency into data use, multilingual data collection and an offline use feature (planned for the future). Formal mechanisms for data uptake by the Rajshahi City Corporation could be the important factor for this impact. Without data uptake, the tool may potentially resemble an academic prototype, rather than implemented as a tool within an institution.

2.13 Expanding the Framework to Other Urban Infrastructure

Although current focus is on road networks, the underlying principles of collaborative monitoring and geospatial analysis are more broadly applicable to urban infrastructure. Sidewalks, sewers, streetlights, and even garbage cans can be placed under the same GIS-enabled participatory monitoring scheme by updating the attribute schema and user interface (Ramesh, 2021; Straub et al., 2016).

In this manner, the research not only fills gaps in urban road surveillance through a collaborative GIS-enabled approach but also offers a basis for urban infrastructure engagement more broadly, resulting in long-term governance and resilience building.

Chapter 3:

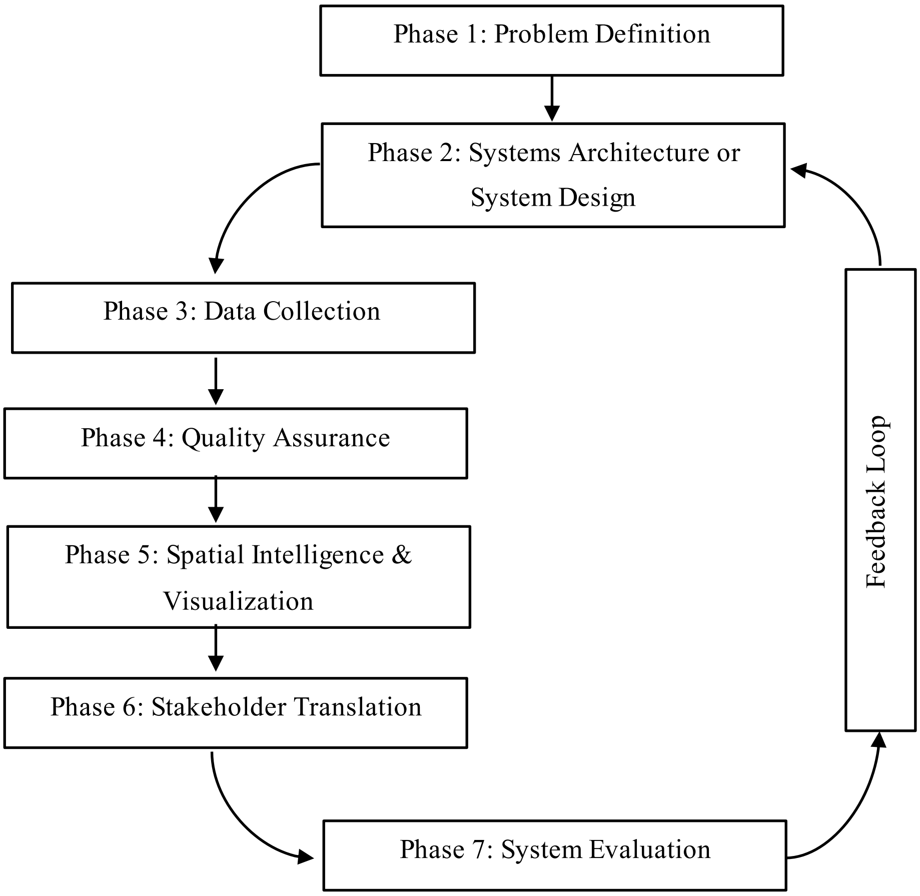
Methodology

Acknowledging the significant need for persistent infrastructure monitoring, this study developed Road Lens - an open access web-enabled platform that integrates public-sourced data collection with interactive visualization. Designed for ease-of-use, the system allows citizens to report road distress while authorities can use it to complete effective spatial analytics in real time to prioritize maintenance. Here, we describe the integrated framework: system architecture, contributor evaluation workflows, geospatial analysis modules, and user experience validation. We describe the entire lifespan of our data - from mobile capture, to quality control, to stakeholder visualization - while establishing rigorous protocols for statistical validation and spatial modeling of data directly and within the platform.

3.1 Overview of the Methodology

This section describes the overview of systematic process through which the RoadLens application was planned, designed, built, tested, and evaluated to monitor road infrastructure. A participatory, GIS-enabled, and web-based approach was used by this research to address the limitations of conventional inspection systems and to organize crowdsourced data for the detection, visualization, and classification of road distress.

This study used a systematic, multiple-phase approach to create and assess RoadLens, an open-source, web-based GIS framework for road infrastructure monitoring. To develop a system for monitoring urban road distresses in developing cities like Rajshahi, this study is structured into seven logically related phases. Following the phased process helps the field's technical components to continue being locally relevant, scientifically relevant, and geographically correct. The methodology is organized into seven crucial phases as shown in Figure 2.1: (1) problem definition/problem formulation, (2) systems architecture or system design, (3) data collection through RoadLens, (4) quality assurance (through contributor assessment and admin verification), (5) spatial intelligence - value added GIS-based analysis, (6) stakeholder meaning-making, translated, and (7) evaluation of the system and framework. These seven phases also allow for a feedback loop so improvements can continuously be developed.



Source: Authors' Preparation, 2025

Figure 2: Methodological Framework

The first methodological phase describes the problem identification, in which the limitations of traditional monitoring systems are described, and the types of road distress typically identified on an urban road network. The second phase is the design and development of the RoadLens system architecture. This integrated digital tool allows registered users (or contributors) to collect data on distress to specify the type of distress using mobile and web interfaces, which enables contributors to upload geotagged images to classify the road distress type and specify the severity of distress, suitable for spatial analysis and maintenance prioritization.

The study combined quantitative (i.e., distress mapping, heat maps) and qualitative (i.e., user feedback, user interface experience) to assess performance. Additionally, a qualitative pilot test was conducted with 20 contributors in Rajshahi City to understand usability better and determine data reliability. With this comprehensive approach, the capacity to assess infrastructure in real-time improves, with aspirations for affecting participatory planning action, community stakeholder decision-making, and future smart urban infrastructure improvement solutions.

3.2 Problem Definition

Road networks serve as essential components of urban infrastructure which supports economic development alongside mobility and service accessibility. Rajshahi along with other fast-growing urban areas demands urgent attention toward continuous road infrastructure monitoring programs. The condition of roads naturally declines because of vehicle traffic damage together with environmental factors inadequate drainage systems and postponed maintenance activities. The initial signs of road deterioration manifest through distress points which include potholes and cracks as well as raveling and edge failures. The minor road defects that remain unaddressed transform into major problems that reduce road safety and usability.

Survey teams conducting manual visual inspections serve as the primary assessment method for roads across all areas of Bangladesh. The current survey method faces constraints because of logistical difficulties financial restrictions and the absence of real-time data collection which affects both survey intervals and geographical reach (Rahman & Hasnat, 2020). The authorities cannot detect road problems because they do not have real-time data collection and limited survey frequency which forces them to perform expensive restoration instead of preventive maintenance.

Different nations have tested citizen involvement in infrastructure monitoring as a solution to their limitations. The combination of participatory sensing with mobile mapping allows citizens to record environmental data through smartphone applications and web-based platforms (Klauser & Albrechtslund, 2014). When properly designed these systems can provide detailed frequent data that enables public institutions to enhance their infrastructure degradation detection and response capabilities. The concept fits within the bigger trend of smart urban infrastructure which uses technology and community engagement to achieve sustainable development goals.

The current participatory frameworks show usability problems that hinder their functionality. Various frameworks need participants to receive training or use complex applications which limits their scalability in developing nations. The study develops RoadLens through a web-based GIS platform that allows any person to submit road distress reports using an organized simple interface. The platform prioritizes user-friendliness together with automatic processing and immediate data transmission capabilities.

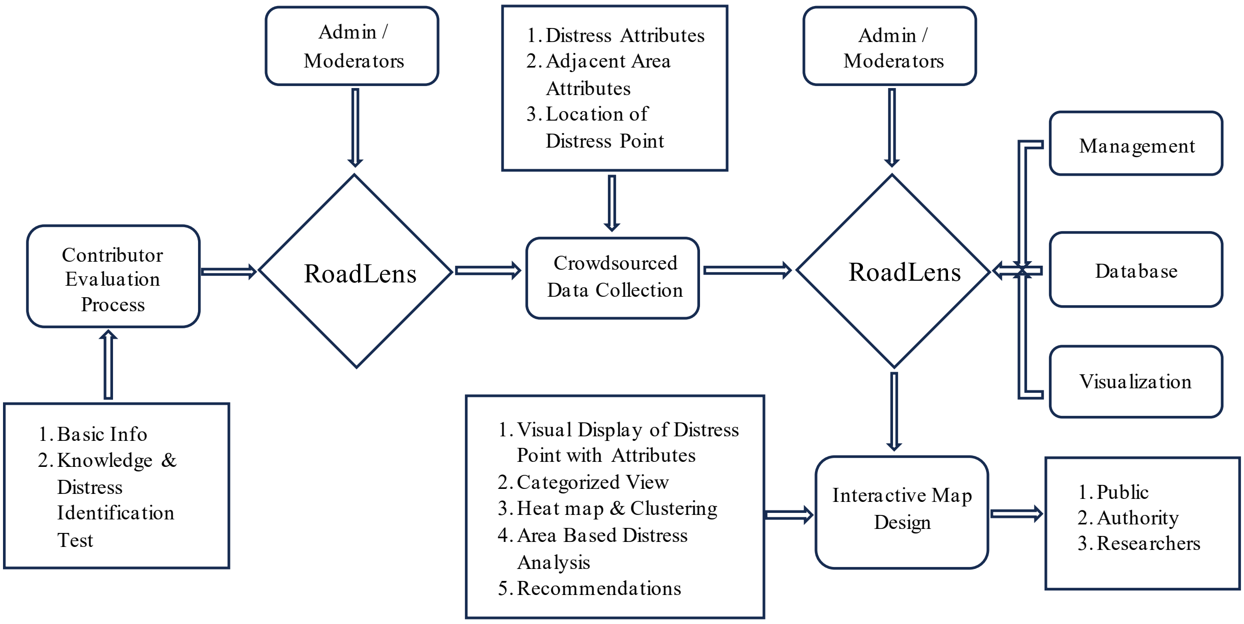
RoadLens achieved its innovative status through its technical components as well as its inclusive participation model. The system integrated geo-tagged image uploads with automated form controls and modular data visualization which benefits both citizen users and institutional stakeholders. The system required contributors to complete a basic evaluation to demonstrate their competency in recognizing road distress types before they submit data. These measures lower the probability of wrong submissions without making the system complicated for users to use. Numerous issues that arise during the system's development and deployment phases must be resolved. Due to users' varying levels of digital proficiency, obsolete mobile devices' lack of GPS capability, and linguistic and validation issues with data processing, the implementation confronts numerous challenges. RoadLens utilized automatic entry functions with graphical interface selection tools combined with language support and backend moderation to tackle these challenges. The application of responsive design enabled product compatibility with different types of devices. Data validation and filtering of reported information can be performed in real time through the administrative dashboards.

RoadLens transferred infrastructure evaluation duties to community members to create an inclusive assessment framework for institutions while delivering cost-effective scalable monitoring capabilities. The system tackled pre-survey obstacles through automated form verification and user-friendly submission procedures alongside immediate GPS validation. Stakeholder engagement received support through open-access data printable reports and institutional dashboards and contributor motivation received encouragement through recognition features. The integrated participatory model establishes a scalable framework that supports sustainable road infrastructure monitoring across developing urban areas. The project creates an inclusive intelligent urban infrastructure management system by uniting participatory mapping principles from Scolamiero et al. (2025) with practical city development solutions from Straub (2016).

3.3 System Architecture of RoadLens

The system architecture presented here describes RoadLens which functions as a web-based participatory platform for gathering crowdsourced road distress data along with its validation and visualization functions. The architectural design aims to provide a modular scalable framework that enables citizens to report infrastructure damage through an easy-to-use interface that delivers actionable geospatial intelligence to urban planners, engineers and policymakers.

The modular design of RoadLens divides its system components into separate functional layers which connect the contributor interface with backend processing geospatial mapping and data storage and administrative validation. The system enables easy data collection from public participants through its structure which converts field information into mapped visual insights accessible to decision-makers. The complete process is depicted in Figure 3 which shows the registration procedure for contributors and the subsequent distribution of data to public users and stakeholders.



Source: Authors' Preparation, 2025

Figure 3: System Architecture of RoadLens

RoadLens uses a client-server model which provides contributors access to the system through the frontend while the backend performs data processing and user session management and connects to external APIs and databases. We chose open-source technologies to create RoadLens because it ensures both cost-effectiveness and system adaptability during deployment. The architecture provides each functional module with independent update capabilities that do not disrupt the rest of the system. The main technological elements of the system receive description in Table 1 which explains the key modules used to build RoadLens together with their platform roles and the reasons for selection.

Table 1: System and Technological Components of RoadLens

Component	Technology Used	Functionality Description
Frontend Interface	EJS templates, Tailwind CSS	Generates dynamic HTML pages and responsive UI for contributors to report distress points.
Backend Server	Node.js with Express.js	Handles server-side logic, API routing, user session control, and form submissions.
Database Management	Supabase (PostgreSQL)	Stores structured data such as distress attributes, user data, image URLs, and coordinates.
Mapping Tools	Leaflet.js and Mapbox	Visualizes distress points on interactive maps with real-time rendering and tile customization.
Image Hosting	ImgBB API	Hosts uploaded images externally and provides URL links for use in dashboards and pop-ups.

Source: Authors' Preparation, 2025

The system includes three key tools which were picked because they easily integrate and perform well in real-time geospatial applications while being open-source or cost-effective to enhance future deployment possibilities. The platform allows contributors to document distress attributes which include type, severity, location, and adjacent land use through its structured recording system. Leaflet.js maps showcase verified distress records through heatmap overlays categorized views and clustering analytics functions. The dashboard interface allows admins to control contributor activities while they verify data and sustain backend system stability.

The architecture enables users to submit data instantly while rendering it spatially and validating it externally before interactive analysis which connects public contributions with institutional actions. The test phase assessment will explore the operational aspects of each module and explain how user participation and system feedback helped improve the system.

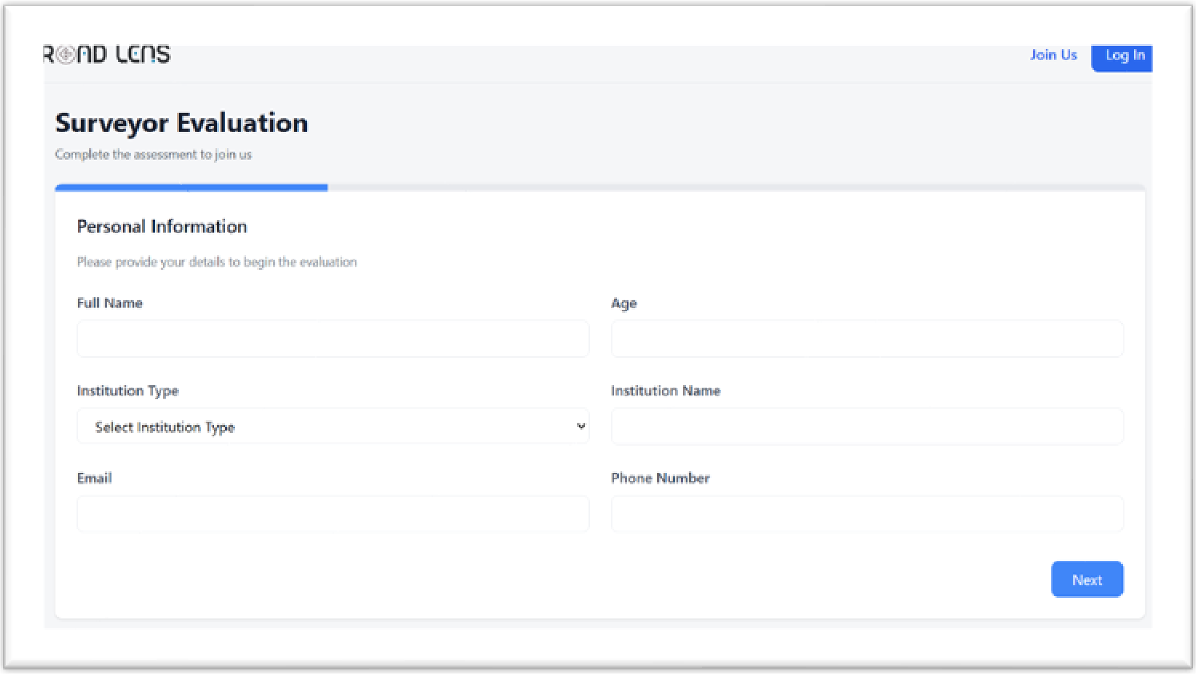
3.3.1 Contributor Evaluation Process

To assess the quality and legitimacy of geospatial data provided through the RoadLens platform, a rigorous three-part contributor assessment system was developed. The assessment process is intended to demonstrate that each contributor possesses a fundamental yet valuable knowledge of the various types of road distress, and the ability to collect and provide accurate, geotagged data. When a new public participant or enthusiast shows interest in contributing to the platform, the participant must be approved by an administrator or referred by an already validated contributor. All contributors must be assessed before being granted full access to submit distress point information.

Before completing the test, there were digital leaflet resources on the RoadLens website that contributors were encouraged to read. These leaflets included simplified images, brief definitions, and example images of typical road distress types (i.e., potholes, cracks, raveling) along with a summary of key survey aspects, including image capture, GPS turn-on, and how to assess the severity of road distress. By examining these resources, we were able to provide baseline knowledge to inexperienced contributors which would improve their chances of completing the evaluation and producing high-quality survey data. So as mentioned previously, the system was designed during the evaluation processes to mimic the entire contribution task flow so that all contributors received the required training and assessment before performing actual data collection.

3.3.1.1 Basic Information Collection

The contributor evaluation process begins by collecting basic demographic and basic institutional information. This step is paramount for a number of reasons not only for keeping track of the number of participants and verifying participation but also for supporting future demographic analysis of contributors' participation, behavior, and accuracy. As illustrated in Figure 4, these fields will require every contributor to provide their eg. a) Name, b) Age, c) Type of Institute and Institution's Name d) Email, and e) Phone number.



Source: RoadLens Website, 2025

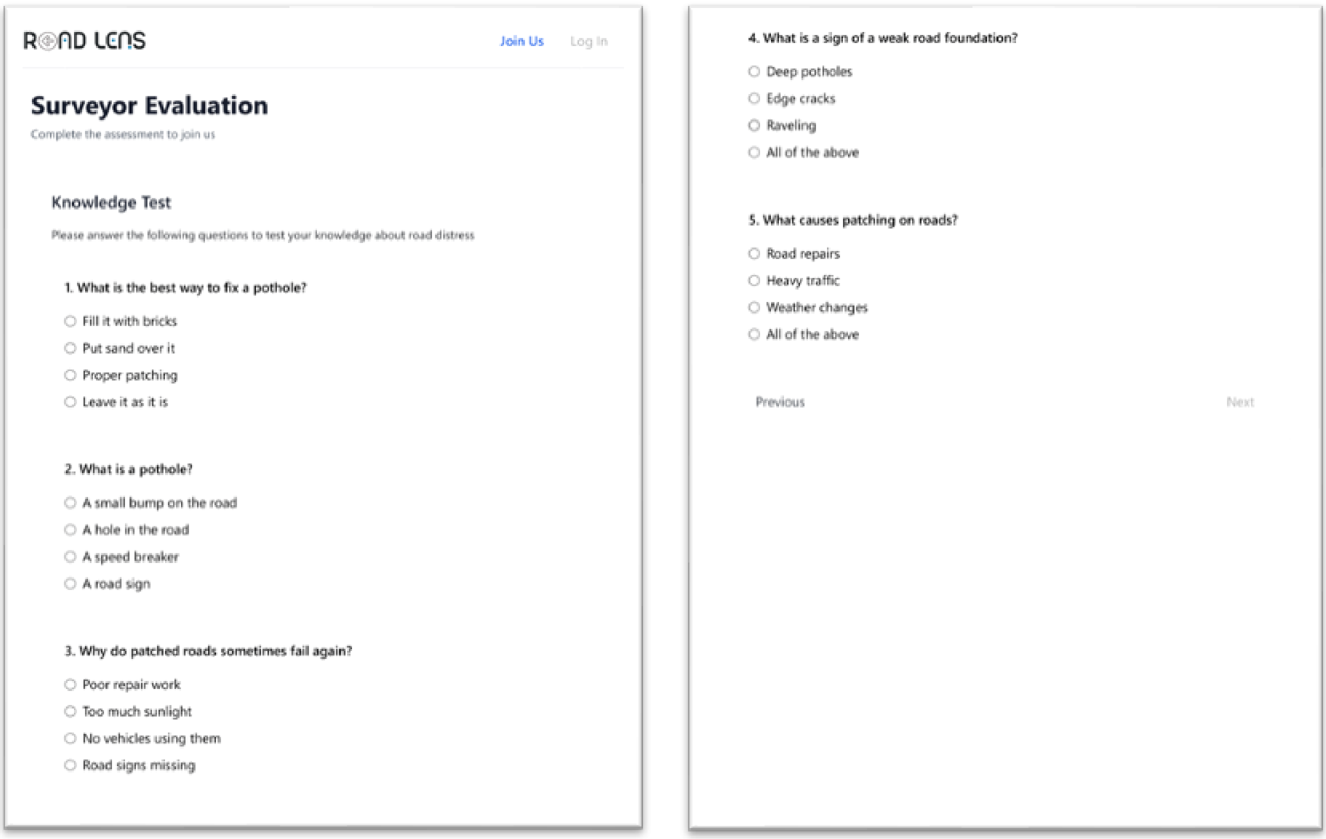
Figure 4 : Surveyor Evaluation Page of RoadLens

While the initial purpose was to account for participation, this data will also allow us to create a structure for future analysis by, for example, segmentation contributors will be able to be segmented based on who they are (or demographics). Once more, the data is validated at the front end, validated at the back end, and stored and secured in our Supabase PostgreSQL database in the evaluator_responses table.

3.3.1.2 Knowledge & Distress Identification Test

Following the demographic step, contributors proceed to a two-tiered assessment designed to ensure they possess the theoretical and observational knowledge necessary to accurately report road distress conditions.

a) Theoretical Knowledge (MCQ Test)



Source: RoadLens Website, 2025

Figure 5: Surveyor Evaluation Knowledge Test Page, RoadLens

In this segment, contributors are presented with five randomly selected multiple-choice questions sourced from a structured Google Sheet as shown in Figure 5, which is managed and updated by the administrative team.

These questions focus on:

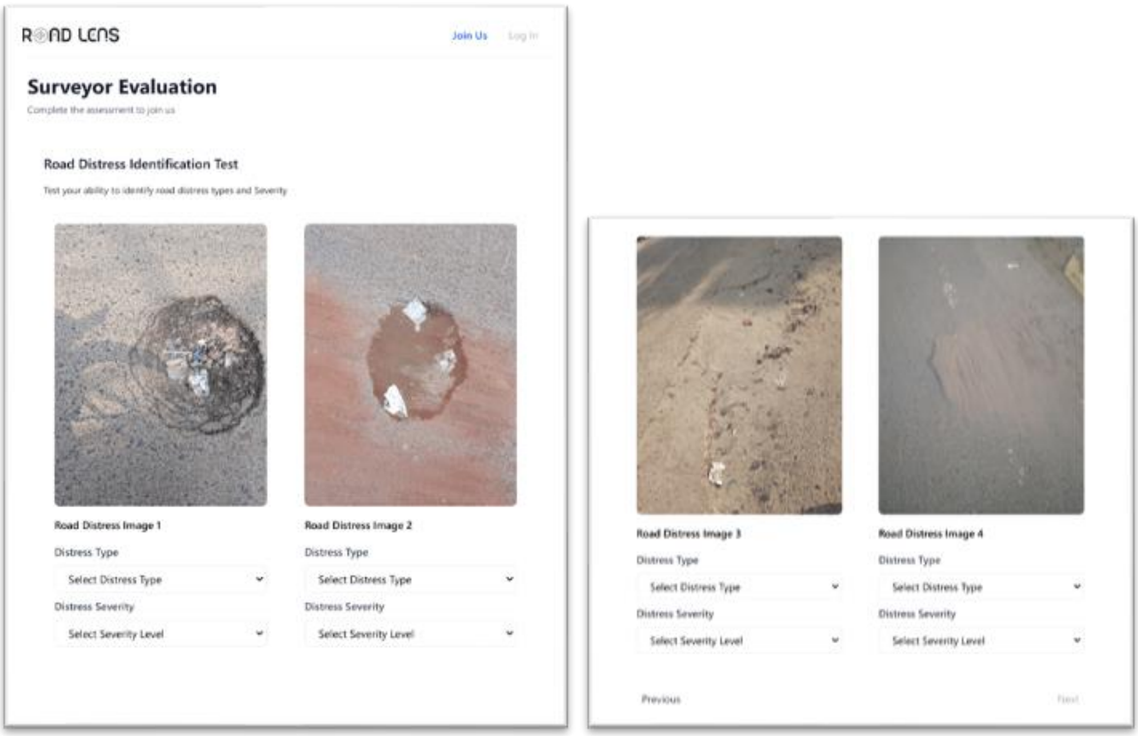
- Definitions of common road distress types (e.g., cracks, potholes, raveling)
- Causes of these distresses, such as poor drainage or traffic load
- Consequences of ignoring such defects
- Standard repair methods and severity classifications

The dynamic CSV parser integrated into the system allows randomized delivery of questions and enables easy question bank modification by admins, ensuring flexibility and relevance over time. This section bridges the gap between academic knowledge and field-level practicality. It evaluates not just theoretical understanding, but also the contributor's ability to visually detect and classify real-world road issues—an essential step for ensuring quality data in large-scale participatory GIS systems.

(b) Visual Recognition Assessment

In the subsequent sub-phase, contributors will see four geo-tagged images that were previously collected by the field surveyors, showing distress in various conditions. Following the example in Figure 6, contributors will be asked to

- Select the correct distress type (e.g., pothole, wide crack, edge crack)
- Choose an appropriate severity level: Low, Moderate, or High.



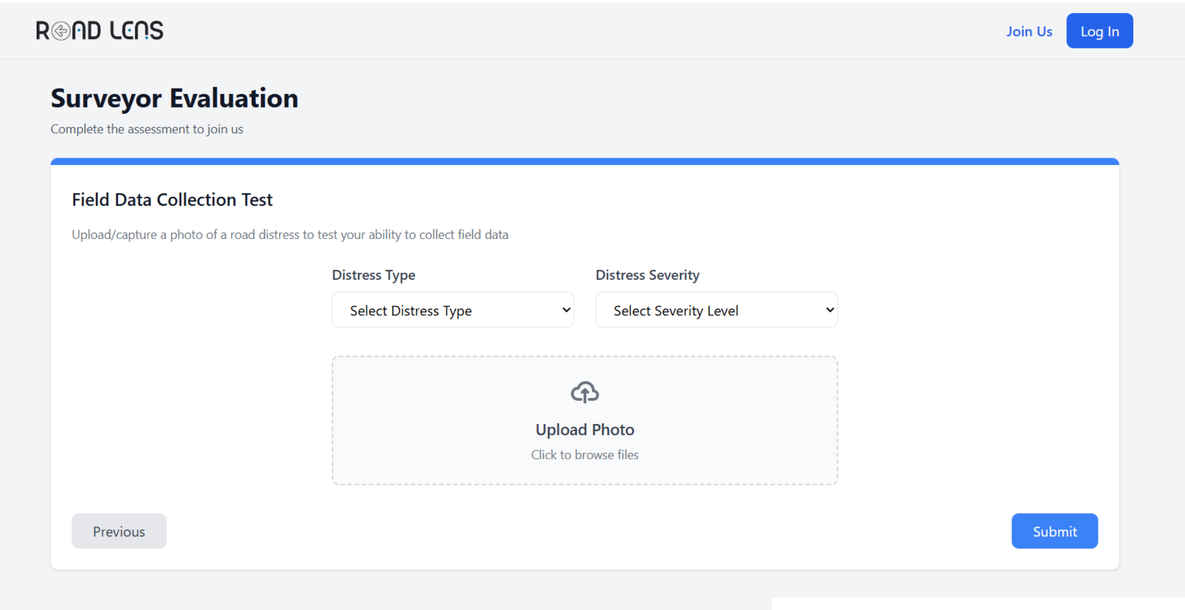
Source: RoadLens Website, 2025

Figure 6: Surveyor Evaluation Visual Recognition Test Page, RoadLens

Responses are recorded in the image_assessment_responses database and will be verified either automatically via logic rules or manually by moderators. This section provides a connection between academic theory and practical application at the field level: it assesses (1) theoretical knowledge and (2) the contribution's ability to detect and classify real-world road issues with pictures—an important part of ensuring quality data for large-scale participatory GIS systems.

3.3.1.3 Field Test Submission

The third and final stage in the contributor evaluation framework combines simulating an actual submission survey and assessing if the contributor can effectively and accurately report road distress independently using the RoadLens platform as shown in the figure 7. This final phase is a performance check in a realistic context of data entry, but prior to giving the contributor unrestricted access to the crowdsourcing interface. It also serves as a practice for contributors to understand how to use the system before participating in road distress data submission.



Source: RoadLens Website, 2025

Figure 7: Surveyor Evaluation Field Test Page, RoadLens

During this contribution evaluation stage, each contributor submits the following:

- A geotagged photo of a legitimate road distress point (for example, pothole, edge crack, patching),
- A categorization of the distress type,
- A subjective level of severity (Low, Moderate, or High), and
- GPS coordinates (collected in real time) of the distress point.

Contributors can either take an image of the road defect using their device camera, or upload a previous picture of the road defect. The photo is sent to the ImgBB API, which is a secure external hosting service. The ImgBB API generates a permanent URL, which is stored in the database to serve as a visual reference point for verification and future analysis.

At the same time, the contributor's device engages the Geolocation API to automatically get the latitude, longitude, and accuracy metadata for the contributor's location. Any geolocation information is also scraped directly from the EXIF metadata embedded in the image file if applicable. The combination of the fallback and layered geolocation methods, altogether result in maximized accuracy and integrity in the geolocation metadata used in combination with the other metadata that document a contributor's experience.

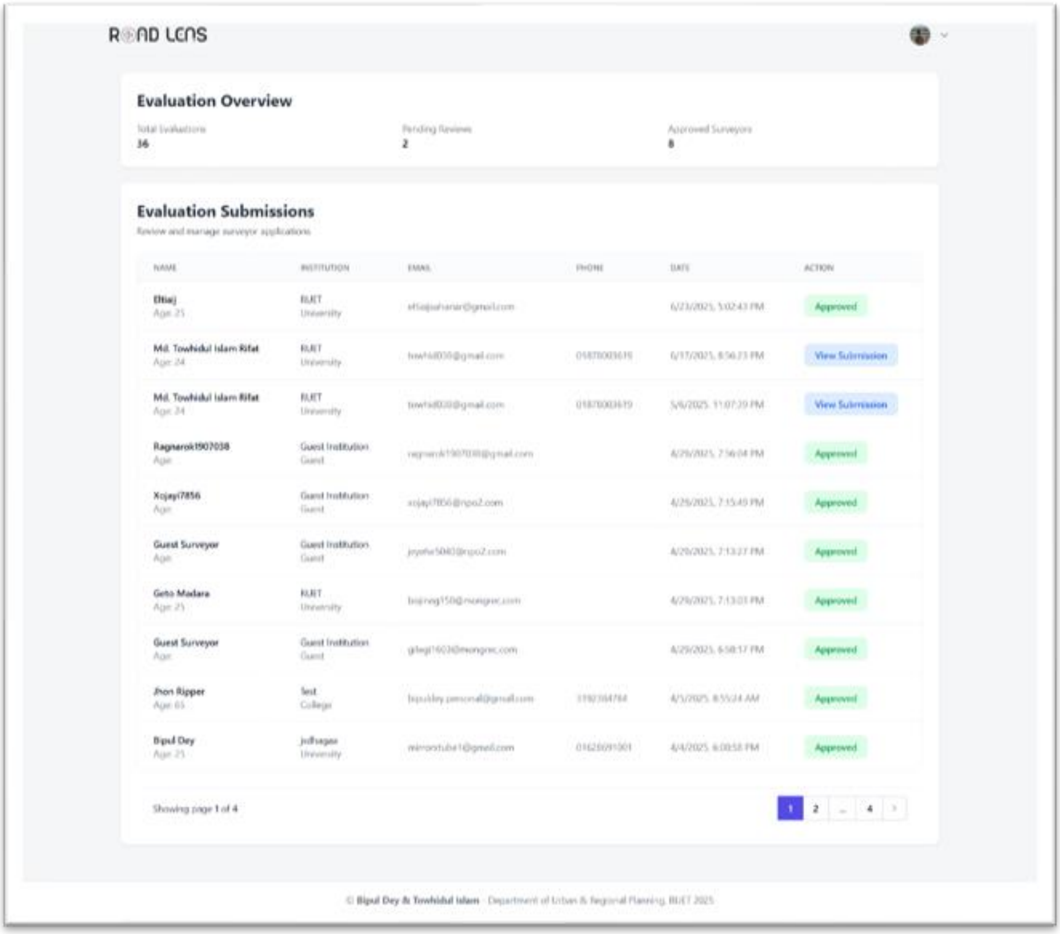
The contributed information, comprising the image URL, distress classification, severity level, and geolocation metadata, is recorded in the field_test_responses table in the Supabase PostgreSQL database. This process ensures that structured means of storing data are being used to maintain reviewer scrutiny of field test results to ensure that only contributors who demonstrate a sufficient level of competency are presented with full access.

3.3.2 Admins/Moderators in Evaluation

The effectiveness and credibility of the **RoadLens** data collection process rely significantly on the role played by **administrators** and **moderators**. These personnel are tasked with overseeing the contributor evaluation process and ensuring the quality and integrity of the data before it enters the central database. Their intervention is particularly crucial during and after the contributor evaluation stages.

Admins access a secure **backend dashboard**—custom-developed as part of the RoadLens architecture—which offers a comprehensive interface for monitoring participant performance across the three evaluation stages as shown in the figure 8. The dashboard provides the following detailed information for each contributor:

- **Evaluator profile** including demographic and institutional details,
- **Auto-scored multiple-choice (MCQ) results**, drawn from the structured Google Sheet question bank,
- **Visual assessment responses**, including accuracy comparisons between user responses and pre-verified ground truths,
- **Submitted field test images** along with metadata such as geolocation and timestamp.



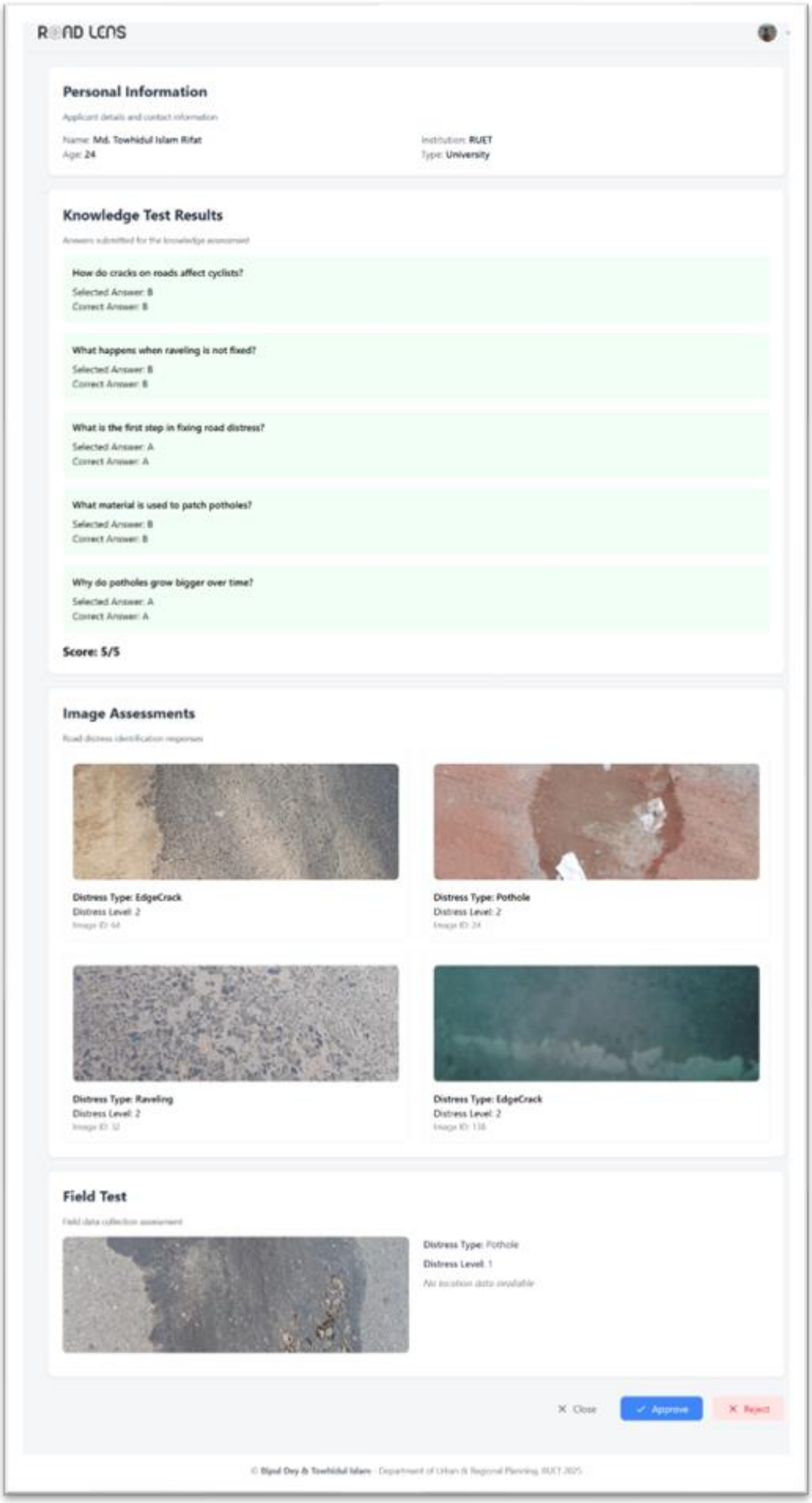
Source: RoadLens Website, 2025

Figure 8: Evaluation Overview for admin/moderators Page, RoadLens

Based on this evaluation, Administrators are able to either approve or reject participants, as shown on the following figure 9. After approving them, contributors will receive an email with their login information and a login guide to use when accessing RoadLens via the survey portal.

Moderators, who are generally technical specialists or senior evaluators, will do an in-depth review of the field test submissions to look into the legitimacy and trustworthiness of the data collected. Examples of the moderator review process include:

- Checking the image type, resolution, and clarity, for compliance with platform specifications,
- Verifying the GPS coordinates to determine if the positional data is accurate, based on defined level of spatial accuracy (typically less than 10 meters),
- Identifying any mismatch between the reported type and level of distress and what was subsequently uploaded in the image.



Source: RoadLens Website, 2025

Figure 9: Surveyor Test Review Page for admin/moderators, RoadLens

This multi-layered review would be the last hurdle before the contributor has full access to the survey tools. This allows for the platform to be populated with verified users who can undertake field surveys to a consistent standard.

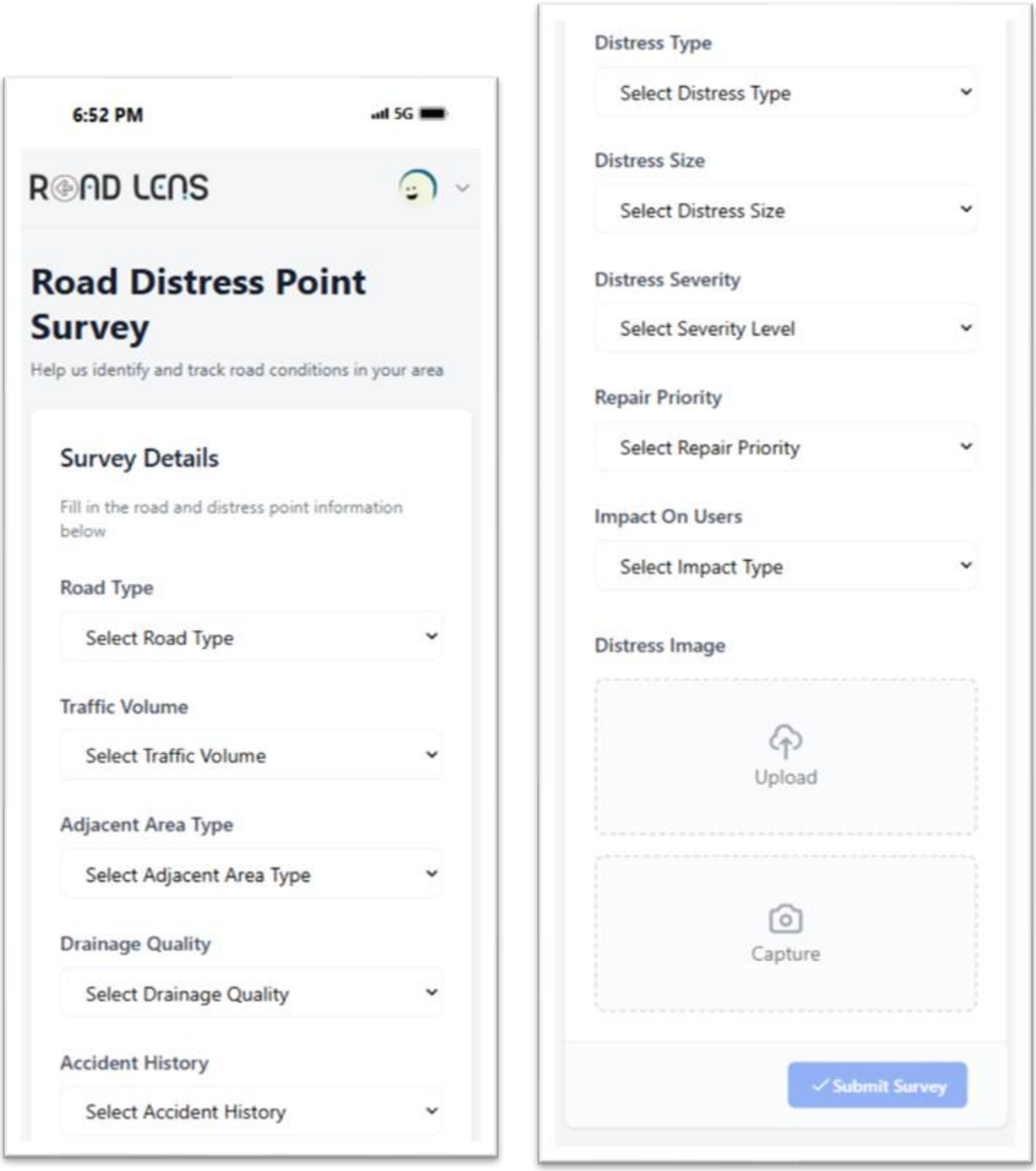
3.3.3 Crowdsourced Data Collection

The RoadLens platform is developed as a public-facing email interface to gather detailed information on road distress conditions from contributors who have been verified. In this section, we outline the formalized procedure for submitting data by the contributor, what information is gathered, and how the contributions are handled and stored in the system. Crowdsourced collection offers a way to provide a scalable, real-time solution to infrastructure monitoring by engaging road users as contributors instead of simply passive users of the road.

3.3.3.1 Collection of Distress Attributes

RoadLens features a standardized digital form that contributors fill out for each submission as shown in the figure 10. This document provides a consistent layout for the reports and a broad spectrum of data attributes of interest for understanding the deterioration of the infrastructure and planning maintenance. Some of these attributes are:

- Distress Type: Contributors select from predefined categories such as pothole, crack, raveling, patching, edge crack, or other. These types represent the most common forms of road surface failure.
- Distress Size: Options are categorized into small, medium, or large to quantify the physical extent of the issue.
- Severity Level: Distress severity is ranked as low, medium, or high, allowing administrators to prioritize repairs based on immediate hazard potential.
- Repair Priority: Surveyors evaluate how urgently the damage needs to be addressed (low, moderate, or urgent).
- Impact on Users: This field captures functional implications such as vehicle damage, safety risks, traffic congestion, or access difficulty.
- Image Submission: Each form requires an image of the distress point, either captured in real-time or uploaded manually.
- Road Type: Contributors select whether the road is a highway, main road, residential, commercial, private/service, or rural.
- Traffic Volume: Traffic flow is rated as low, medium, or high based on observation.
- Drainage Quality: Evaluated as good, moderate, or poor depending on surface water behavior.
- Accident History: Contributors indicate whether the segment has a known record of accidents (yes, no, or unsure).



Source: RoadLens Website, 2025

Figure 10: Road Distress Point Survey Page, RoadLens

All inputs are collected via dropdowns to ensure data integrity and uniformity. Uploaded images are stored externally via ImgBB API and referenced by secure URLs in the Supabase PostgreSQL database.

3.3.3.2 Adjacent Area Data

Land use is also an important context for analyzing distress patterns. Assessors have to specify the type of area adjacent to the documented situation-type from the following classes of area: residential, commercial, industrial, educational institution, medical institution, religious area, government area, mixed use, or open space area. This step adds value to the backend analytics to categorize zones of functional significance and could also assist in priorities for maintenance plans.

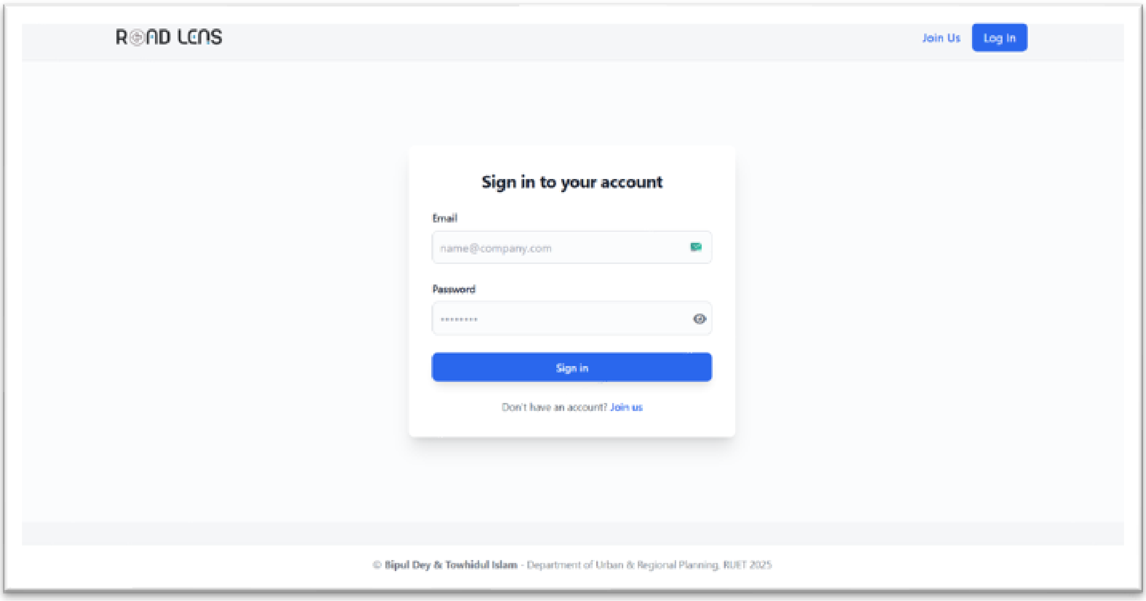
3.3.3.3 Location Mapping and Geotagging

Geolocation is automatically captured via the browser's native Geolocation API, which provides latitude/longitude and accuracy. This means that the assessor does not have to drag a pin, which reduces the time (and possibility for error) with completing requests. The collected coordinates are not immediately reverse geocoded; however, they are leveraged subsequently for map-based analytics, cluster building and temporality.

3.3.3.4 Contributor Interface Workflow

The data collection process has been streamlined for contributors through a step-by-step interface as shown in the figure. The process is as follows:

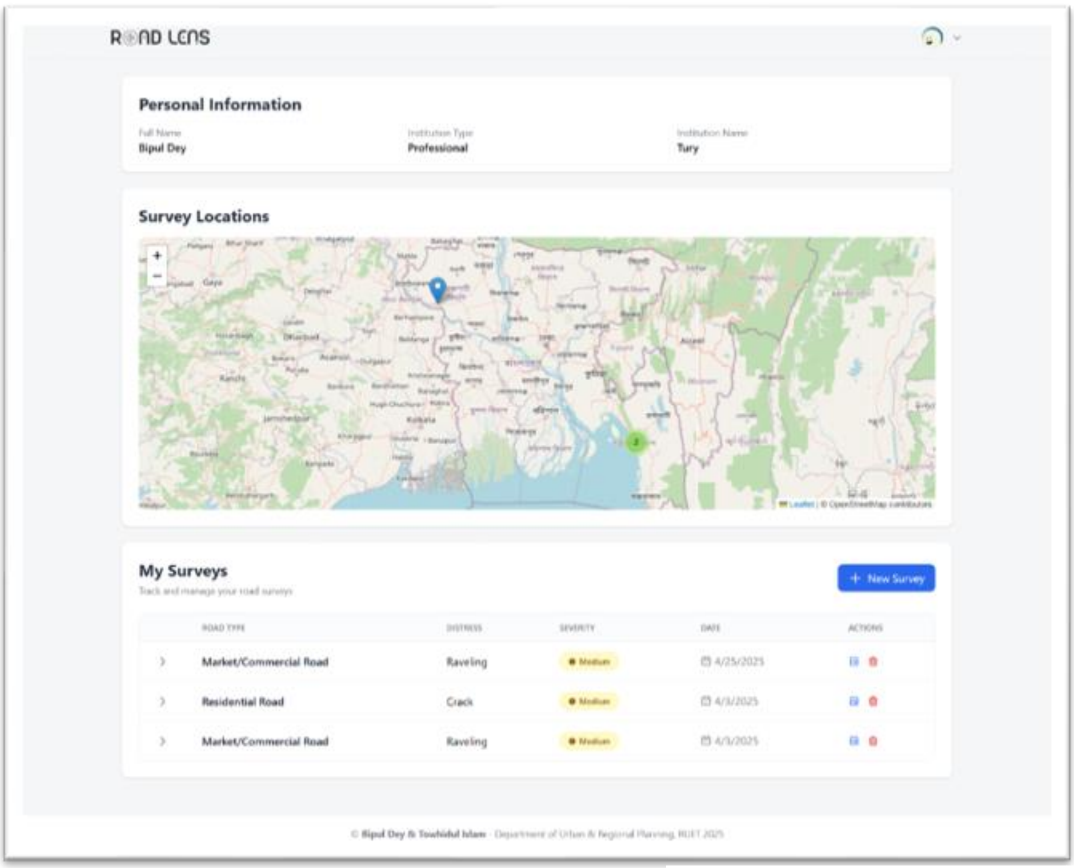
- Login or Registration: Only users who have successfully completed the evaluation process are granted access to the survey form.
- Form Completion: Contributors fill in the distress attributes through dropdown menus, ensuring accuracy and uniformity.
- Image Submission: Users can either capture an image using their mobile device or upload one manually.
- Location Capture: Upon submission, the device automatically transmits the user’s current GPS coordinates.
- Form Submission Confirmation: A success message appears upon a successful upload, indicating that the data has been securely stored.



Source: RoadLens Website, 2025

Figure 11: Login or Registration Homepage, RoadLens

All submitted entries are tied to authenticated user accounts—anonymous submissions are not permitted to maintain data quality and accountability. While there is no real-time status



Source: RoadLens Website, 2025

Figure 12: Surveyor Homepage in RoadLens

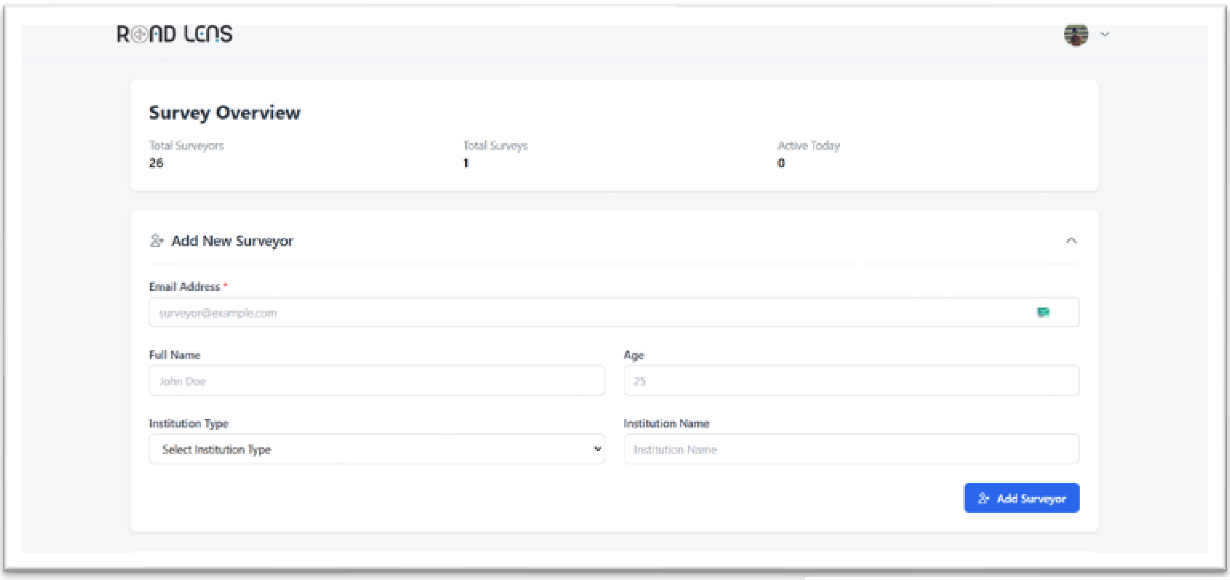
tracking, contributors can revisit and manage their reports through the "My Surveys" section of the dashboard as viewed in the following figure 12.

All submissions are associated with authenticated accounts. Anonymous submissions will not be allowed to maintain data quality and data traceability. Contributors, can later see their submissions in the "My Surveys" section that will include:

- A Map View showing all survey points in a spatial view using Leaflet.js
- A Table View showing each survey's metadata in a table that would enable contributors to review and delete their previous submissions if they desired.

This two-tiered interface enhances transparency and contributor engagement, while also serving as a self-monitoring mechanism for long-term participation.

Admins can utilize the manual adding of a contributor through specifying their email, as demonstrated in the figure, in addition to the evaluation-based entry. The manual entry method can be advantageous when onboarding trusted colleagues or experts without their completing the full evaluation process. This way can provide a more expeditious, flexible collaboration especially with field partners or local authorities, and maintains the growth of contributors in a way that does not affect control or quality standards. This structured crowdsourced data entry process allows for standardized and geo-referenced data collection that is useful data for the broader analysis and evidence based decision-making process for RoadLens.



Source: RoadLens Website, 2025

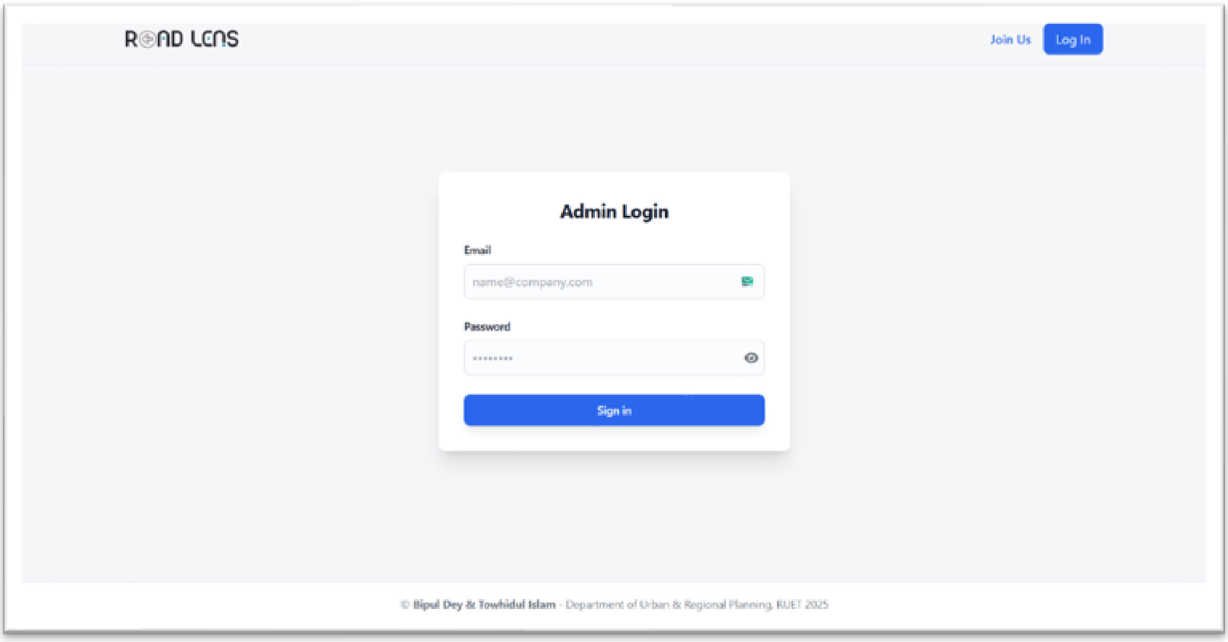
Figure 13: Survey Overview Page for Admin Override, RoadLens

3.3.4 Data Review and Moderation

In order to ensure the long-term viability and usability of crowdsourced data in the RoadLens system, a data quality assurance framework was designed and implemented. In addition to initial moderation by admins to control inaccurate or incomplete submissions, the data quality assurance framework uses automated backend verification, contributor ownership features, and user interactive feedbacks as additional systems to further check data quality assurance. Even with moderation, visitors to RoadLens must be able to rely on the accuracy of data at the point in time when they are able to view it (placing guardrails around data entry and the analysis and visualization of the data). In this section we outline the framework, protocols and logic for quality assurance of RoadLens data over time.

3.3.4.1 Admin Roles and Permissions

The data review and moderation mechanism within RoadLens is conducted via a secured administrative dashboard. As shown in Figure 14, this dashboard is only accessible via credential-based login, with all administrative sessions authenticated via registered emails and secured via HTTP-only session cookies.



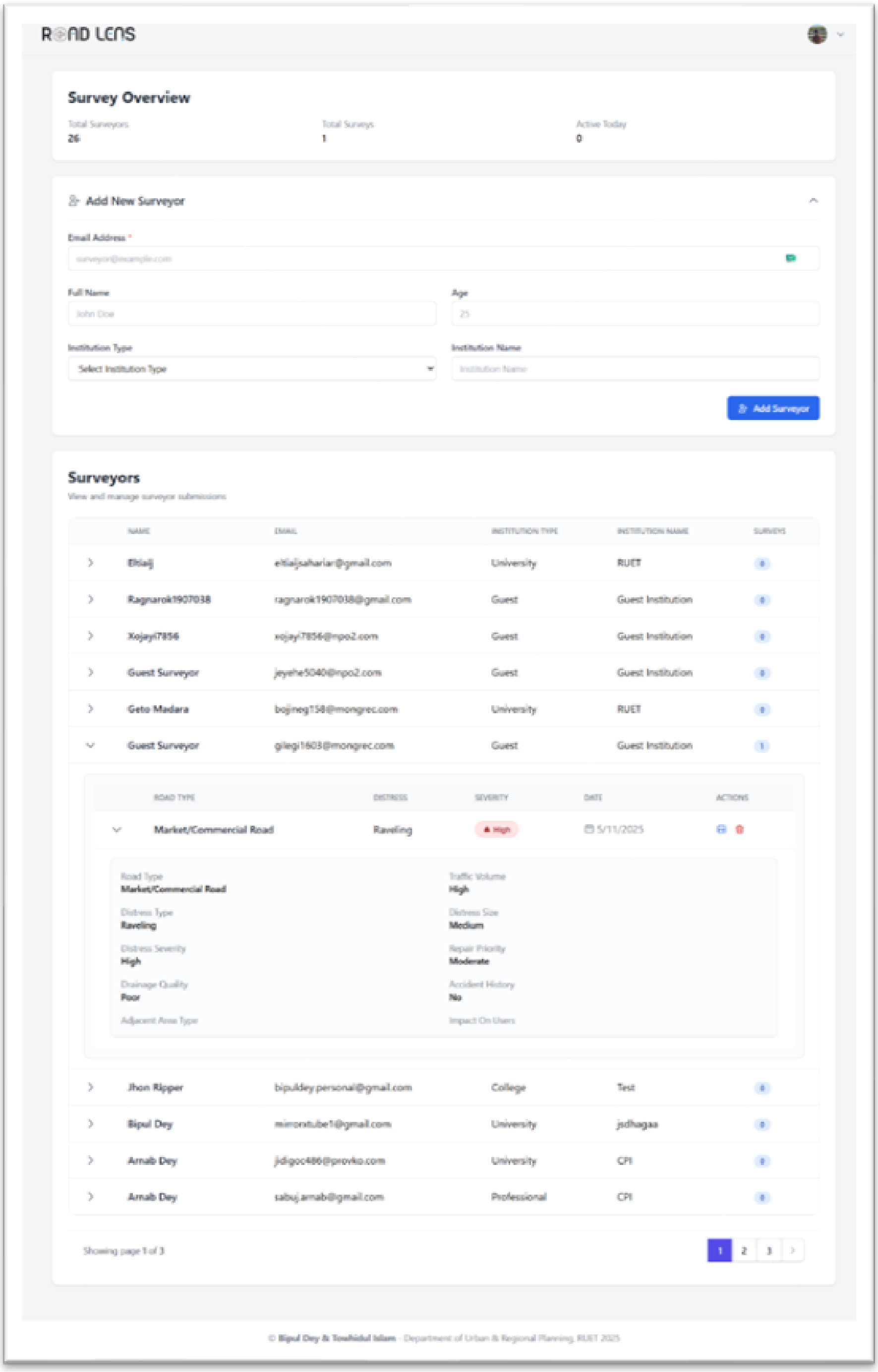
Source: RoadLens Website, 2025

Figure 14: Admin Login Page

Admins are authenticated via email and session cookies, and they have full moderation authority and data rights. There is no "moderator," only an administrative function performed by users who are logged in as admins, as discussed in the pictorial above.

Admins are authorized to:

- View all submitted surveys and evaluator applications.
- Approve or reject evaluator registration.
- Manually add surveyors.
- Delete any survey record.
- Resolve user-submitted reports.



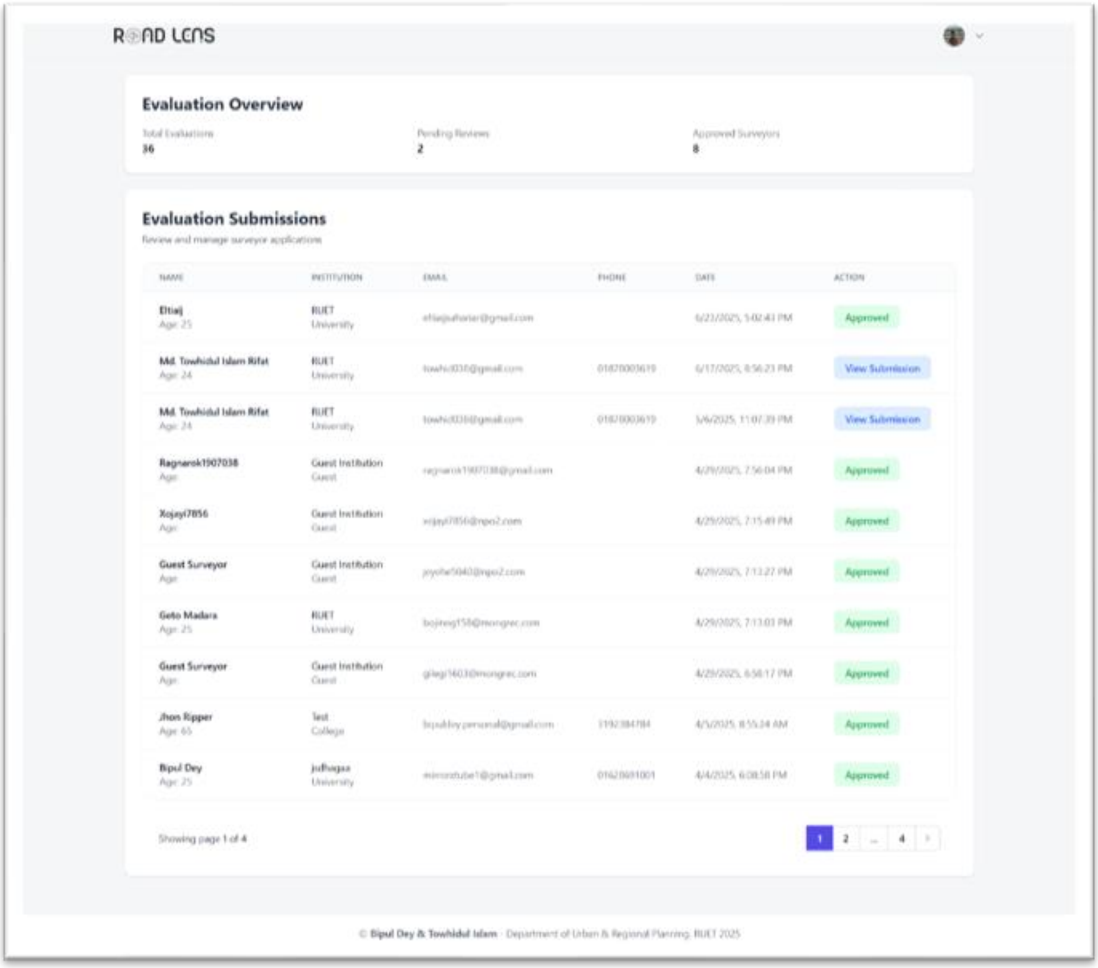
Source: RoadLens Website, 2025

Figure 15: Admin Homepage in RoadLens

3.3.4.2 Survey and Evaluator Moderation

In the RoadLens system, data review and moderation are vital components to ensure the reliability and usability of the crowdsourced road distress data. This process functions at two distinct levels: evaluator moderation (user-level) and survey moderation (data-level), both of which are managed through a secure administrative interface.

Evaluators' applications are evaluated by admins first, via their own dashboard as shown in the figure 16. Each application includes demographic information and evaluators evaluation (MCQ, image evaluation, and field test submissions). Once an application is approved, the system automatically sets the user as contributor, and an onboarding email is sent with links to create password or update password. If the application is not approved, then it will be marked in the database for internal reporting/government requirements as “rejected” however a rejection response email will not be sent to the applicant. This is to ensure that anyone who contributes to the system must be a qualified and verified user, and to maintain the system and database free from spam and poor-quality contributions.



Source: RoadLens Website, 2025

Figure 16: Submission Overview Page by Admin, RoadLens

Survey Submissions are monitored in real time through the admin panel, which includes detailed metadata such as distress type, severity, road type, adjacent area context, and GPS-tagged map visualization. Administrators can open any individual survey record to validate image quality, review positional accuracy, and examine content relevance. While survey entries cannot be edited post-submission—ensuring data authenticity—they can be deleted if found to be erroneous or irrelevant.

Furthermore, RoadLens incorporates a report resolution mechanism. Contributors can flag questionable or incorrect survey entries. These flagged submissions are immediately highlighted in the admin dashboard. In the first instance, the admins will review the flagged entries and if fully warranted they will designate it "resolved." They also have the option of recording their notes on the nature of the issue (e.g., miscategorized, blurry image, incorrect location). The moderation is transparent which supports ongoing quality management of data after it has been submitted.

3.3.4.3 Notifications and Feedback

- To Admins: No real-time in-app notifications exist for new submissions or reports.
- To Users: Approved evaluators receive an email upon acceptance.
- System Feedback: UI feedback (e.g., success or error messages) is delivered via toast-style modals using SweetAlert2 for most admin actions.

3.3.4.4 Moderation Dashboard and Tools

Admin dash board includes:

- Overview statistics (e.g., total number of surveys, active users).
- Interactive map that clusters markers used to show the locations of surveys.
- Two types of displays for surveying management: table and card.
- Modal for adding users or deleting submissions. Separate views for evaluator applications and user-submitted reports.

The dashboard offers basic interactive tools, but does not currently provide advanced filtering based on distress attributes, or the ability to perform batch moderation actions. All actions (approving, rejecting, deleting) are performed on an individual basis.

Ultimately, the moderation system, whether it assists with maintaining high levels of data quality, user accountably, and user transparency by auditing, manual review, and decision-making by verified administrators.

3.3.5 Database and Data Management

Efficient database and data management practices were critical to ensuring that the RoadLens platform could support real-time data collection, secure user interactions, and seamless integration of geospatial information. The following subsections describe the design decisions, backend implementation, image handling, authentication measures, and backup strategies adopted to achieve these objectives.

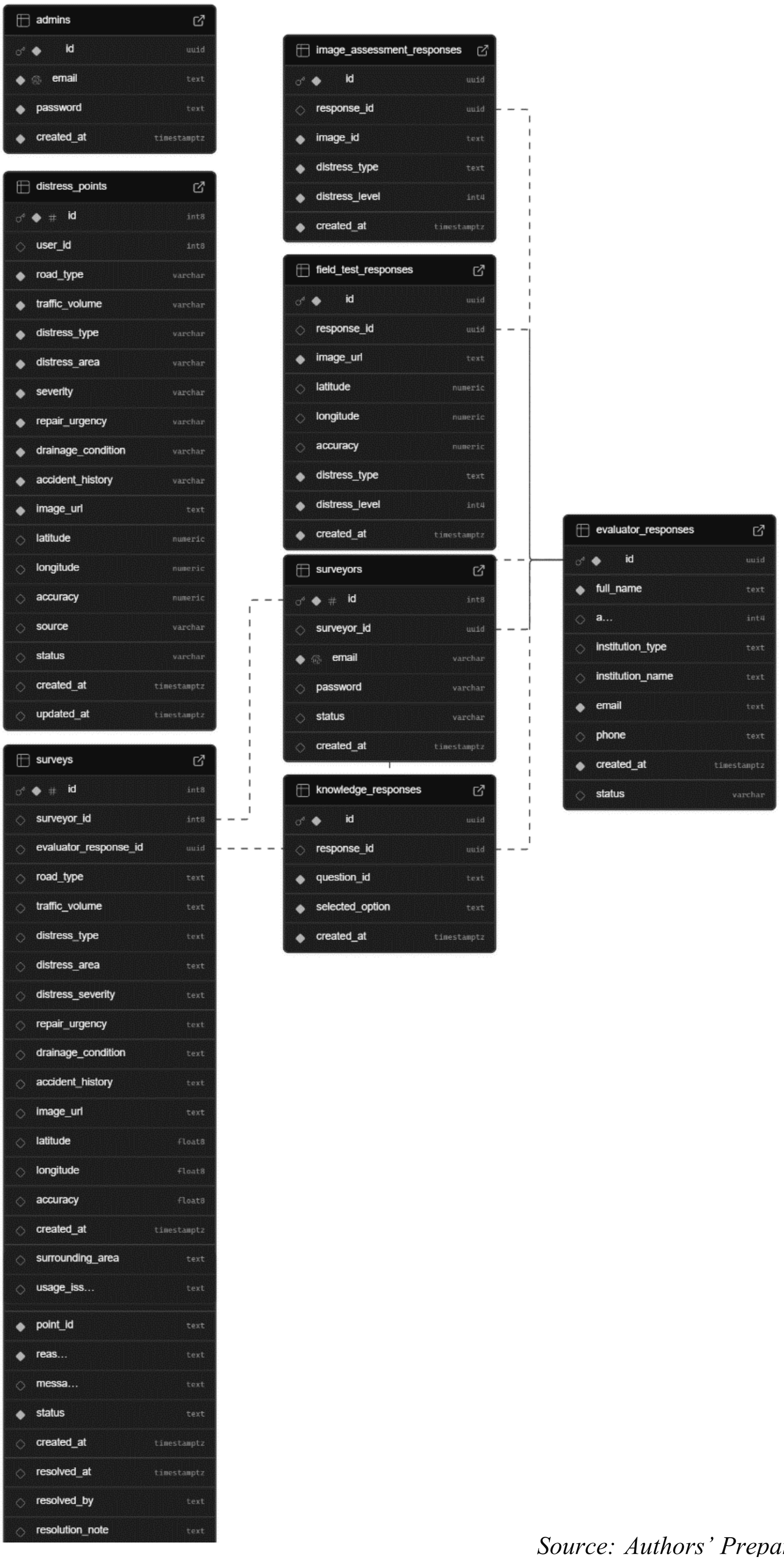
3.3.5.1 Database Architecture

The RoadLens platform had used Supabase, a backend-as-a-service built on PostgreSQL, as its primary database. Supabase had provided both relational database management and secure API access. The backend had communicated with Supabase using the @supabase/supabase-js client.

Key Tables:

- surveyors: This table is where we store the login information and static metadata for all approved contributors to the platform
- evaluator_responses: It registers the answers and personal data for users who are signing up to be surveyors
- surveys: The core table where the road distress data is stored, containing those distress attributes, images, and geo-location.
- reports: This table holds the flags and issues submitted by users regarding the existing surveys
- admins: Contains credentials for platform administrators.

Each table has unique identifies and relationships between them by foreign keys to keep everything consistent. For instance, surveys have relationships with surveyors and evaluator_responses with foreign keys. The complete frame work is displayed in figure 17.



Source: Authors' Preparation, 2025

Figure 17: Database Architecture of RoadLens

3.3.5.2 Backend Framework and API

The backend is built using **Express.js**, a lightweight web application framework for Node.js. It uses a modular route structure to define RESTful APIs. Key endpoints include:

- **User Actions**: /submit-survey, /report-distress, /set-password/:token
- **Admin Actions**: /admin/approve/:id, /admin/surveys/delete/:id
- **Authentication**: /login, /register, with session handling and bcrypt hashing for passwords

All APIs follow standard REST conventions and interact with Supabase through the Supabase client SDK.

3.3.5.3 Image Handling

User image uploads are sent to ImgBB via its API, and the application receives a public image URL back from ImgBB, which is subsequently saved in the image_url field of the surveys table. Ali and hoopla built the database so it is lightweight while retaining all survey uploads as metadata, not raw media.

3.3.5.4 Authentication and Security

- **Surveyor Accounts:** Passwords are securely hashed using bcrypt, and sessions are managed with express-session.
- **Admin Accounts:** Currently use plain text matching (a limitation to be addressed in future versions).
- **Token-Based Password Reset**: JWT tokens are used for generating secure, time-limited password reset links.

3.3.5.5 Data Integrity and Backup

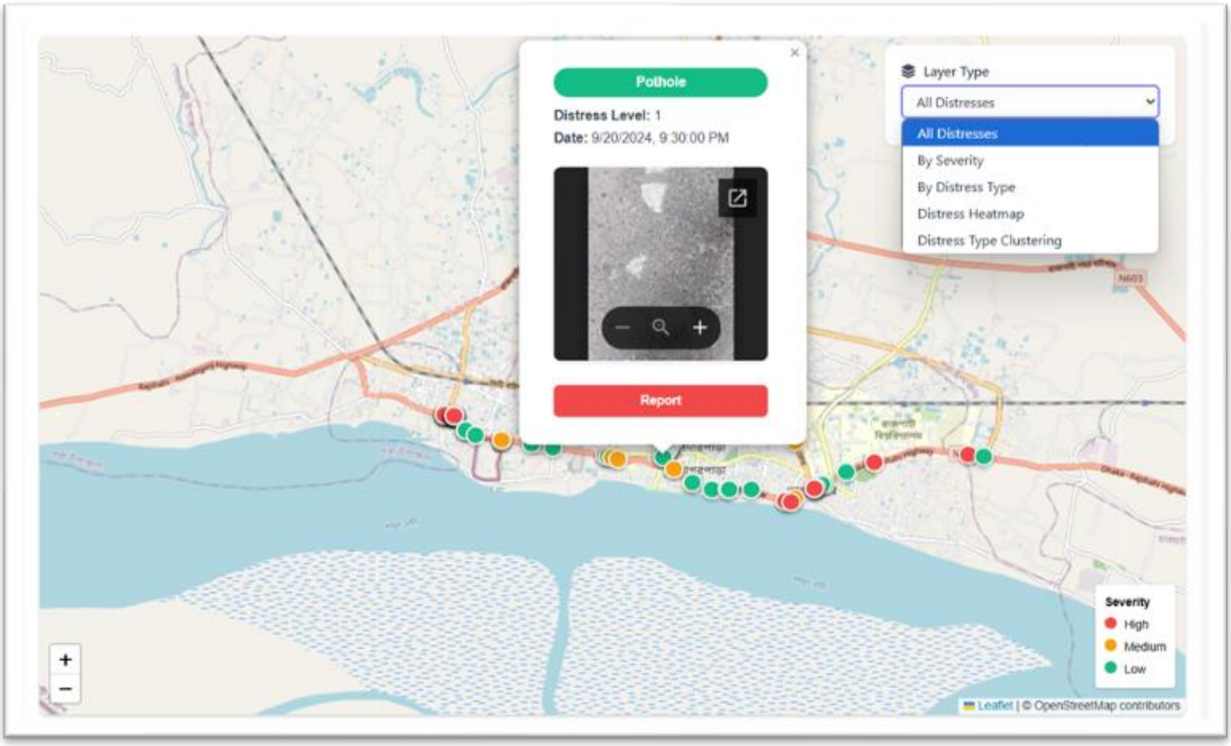
Supabase handles automated backups and data integrity via the PostgreSQL layer, but within the custom codebase:

- There are not soft deletes; deletes are permanent.
- Flagged reports are kept and the status can be changed to "resolved," rather than simply removing them.

This approach, combined with manual moderation and access control, ensures a reliable and secure data architecture suited to the platform's objectives.

3.3.6 Interactive Mapping and Visualization

The mapping and visualization element was a key component of the RoadLens platform, allowing both contributors and administrators to visualize the survey data spatially, with the option to interactively view distress points, see changes to issues as they happen, and filter, all through web-based geospatial capabilities. The interface allowed multiple map styles to support decision-making, as well as a way to show different data layers to help identify areas of greatest need. Figure 18 is an example of the interactive map interface developed specifically for this study.



Source: RoadLens Website, 2025

Figure 18: Interactive Mapping and Visualization in RoadLens

3.3.6.1 Mapping Platform

RoadLens uses Leaflet.js as the mapping library of choice when displaying all geospatial data. It is accompanied by:

- Leaflet.markercluster for optimal clusters to multiple points
- Leaflet.heat for 'heatmaps'
- OpenStreetMap as the tile provider for the base maps.

These modules are incorporated into both the user and admin interfaces.

3.3.6.2 Map Features for Users

Distress Point Markers: Displayed with color codes based on severity:

- Red: High severity
- Orange: Medium severity
- Green: Low severity

Popups: Each marker has popups that include the distress type, severity, size, when distress was reported, a photo if available, and a “Report” button.

Filtering and Layer Control: Users will be able to filter points by severity or type of distress, and toggle through the following:

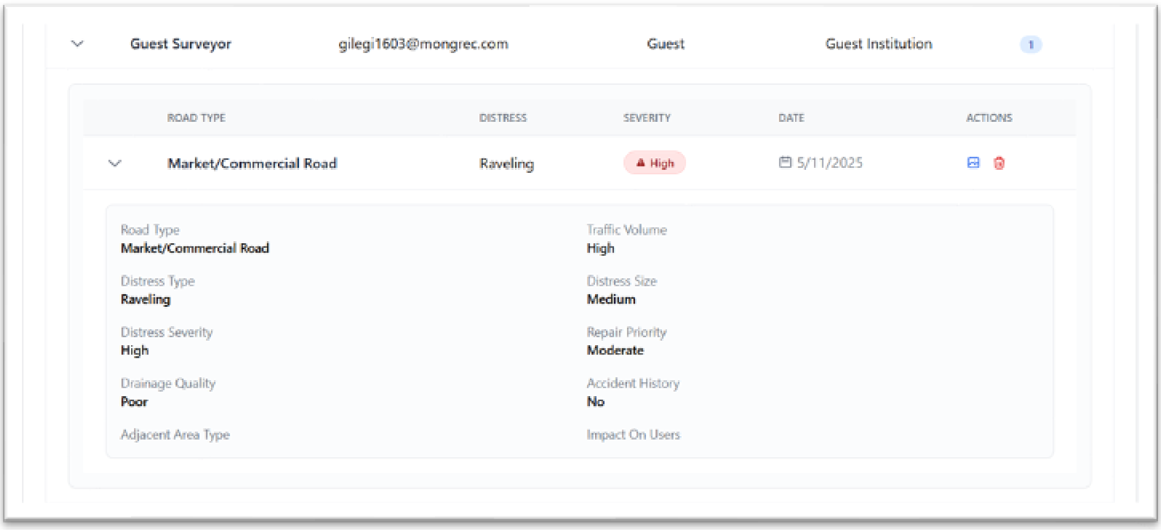
- Raw markers
- Clustered view
- Heatmap view
- Distress type clusters

Legend: A custom legend is rendered for users to interpret marker colours.

3.3.6.3 Map Features for Admins

Admins have access to expanded mapping capabilities as shown in the figure 19 of admin map interface with extended administrative tools:

- View all surveyors’ submissions, each geotagged and clustered
- Visualize evaluator distribution and status
- See and resolve flagged reports directly from the map interface
- View surveyor-specific clusters to understand coverage



Source: RoadLens Website, 2025

Figure 19: Features for Admins in RoadLens

3.3.6.4 Data Flow and Filtering

- **Data Source**: Distress data is sourced directly from Supabase.
- **Client-side Filtering**: All filtering of map layers (by severity, type, etc.) is done on the frontend using preloaded JSON

The map is primarily intended for a visual lens and engagement tool not in-depth spatial analysis. However, the architecture of the map can incorporate future tools, regional overlays, automated report modules and perhaps analysis.

3.3.7 Public Participation Interface

Public engagement had been key to the RoadLens platform. The public interface was designed to facilitate wide user participation, transparency, and community stewardship of the urban road monitoring task. Further, the system had been designed to cater to a wide variety of users, walking them from registration to active surveying of urban roads, with motivational features and continuous feedback about completed surveying to encourage on-going contributions.

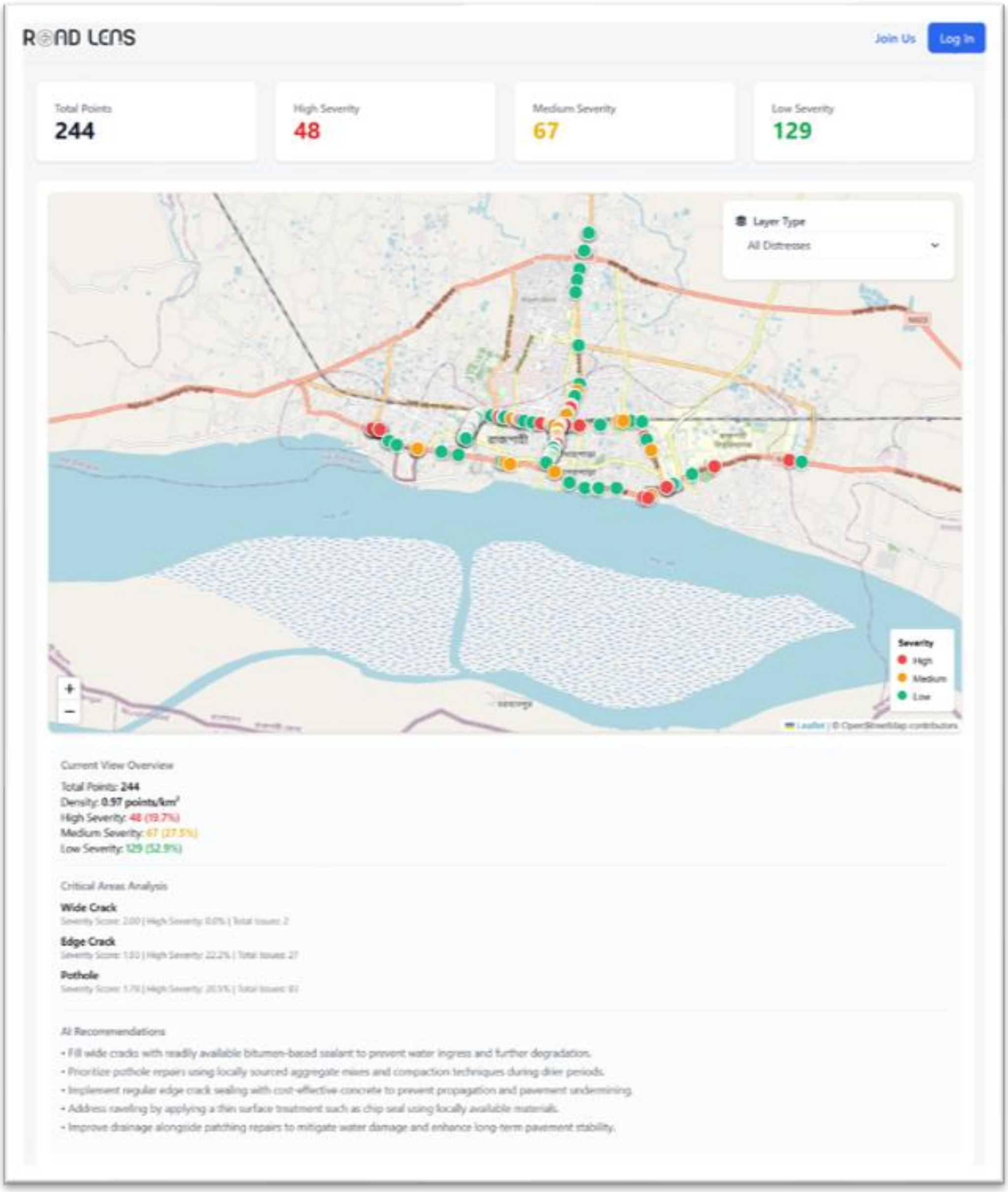
3.3.7.1 Landing Page and Public Access

The RoadLens platform had welcomed all users with a visually engaging landing page that had also served as the public map interface. This homepage had featured an interactive Leaflet map that displayed all reported road distress points using clustering, heatmaps, and filtering options, as shown in Figure 20.

Dynamic statistic cards had summarized key data at a glance, such as the total number of distress points and their severity distribution (high, medium, and low).

We had a dedicated Top Contributors section that prominently featured leading contributors by showing attached avatars, names, institutional affiliations, survey counts, and achievement badges (Gold, Silver, or Bronze). The badges served as motivators for community contribution for users in the community.

In addition, we had a bold formation of a navigation bar that included links to login and register the sites branding. It was important that all public-facing features were fully accessible without requiring someone to be authenticated. This latter situation was to facilitate the public awareness and engagement as much as possible.



Source: RoadLens Website, 2025

Figure 20: Landing Page and Public Access, RoadLEns

3.3.7.2 Evaluator Application Process

Prospective contributors undergo a structured evaluation via a dedicated route (/evaluation). The evaluation form is designed as a multi-step process to ensure quality participation. It consists of sequential sections including personal information, knowledge-based questions, image assessments, and a practical field test.

A visual progress bar prominently displays the user's advancement through the evaluation steps, preventing users from skipping any part. Validation is enforced at each step before users can proceed, ensuring data completeness and reliability in the application process.

3.3.7.3 Survey Submission Interface

Registered surveyors use a mobile-friendly distress reporting form optimized with responsive Tailwind CSS layouts. All inputs, dropdowns, buttons, and interactive elements such as image upload and geolocation capture are designed for ease of use on both desktop and mobile devices.

The form interface includes clear labels, placeholder text, and occasional helper tooltips (e.g., guidance on image upload quality or location accuracy), which help users' complete submissions accurately without overwhelming them.

Upon successful survey submission, users receive immediate feedback via a success message displayed as a toast notification or modal. They are then redirected to their personal dashboard or "My Surveys" page, where their new submission appears instantly in the list and on associated maps.

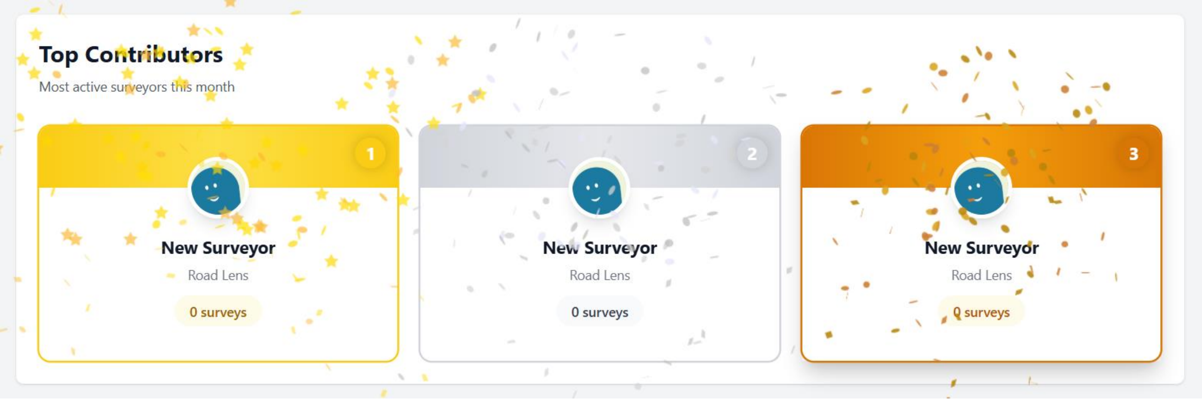
3.3.7.4 User Feedback and Contribution Tracking

Users have access to comprehensive feedback on their participation. The homepage's statistics cards provide real-time updates on total distress points and severity categories. Within their personal dashboards, surveyors can view detailed submission histories with individual entries clickable for expanded details and map visualization.

The "My Surveys" page acts as a personalized log, enabling users to monitor their reporting activity over time, fostering a sense of ownership and ongoing engagement.

3.3.7.5 Gamification and Motivation

To encourage active participation, RoadLens features a gamification system that highlights top contributors directly on the homepage. Users earn visually distinctive, animated badges based on the quantity and quality of their contributions, reinforcing positive behaviour in a fun and engaging way as viewed in the figure 21. While the platform does not use a traditional point-based levelling system, the combination of badges, public rankings, and playful touches like confetti animations on click creates a delightful user experience. These small yet thoughtful elements not only celebrate each user's input but also build a sense of community, appreciation, and purpose. This approach makes contributing feel rewarding and enjoyable, fostering sustained engagement and civic pride.



Source: RoadLens Website, 2025

Figure 21: Gamification and Motivation for the users

3.3.7.6 Language and Mobile Responsiveness

Currently, the platform's interface is available exclusively in English, with no support for Bengali or other local languages. However, we are actively working on developing a Bangla version of the evaluation process, and a fully translated Bangla version of the entire website will be launched soon. This multilingual approach is expected to significantly enhance accessibility and inclusivity, especially for community members who are more comfortable using their native language. By removing language barriers, the platform can better engage a broader demographic, encourage more diverse participation and make it easier for users from all backgrounds to contribute effectively.

All pages and functionalities are fully responsive, ensuring optimal usability across a wide range of mobile devices. Built using Tailwind CSS, the platform smoothly adapts to different screen sizes and resolutions. Mobile-friendly features such as interactive map controls, form inputs, navigation menus, and dashboards ensure a seamless user experience, even on smaller devices. This mobile responsiveness plays a key role in enabling on-the-go participation, particularly in fieldwork scenarios or areas with limited access to desktop computers.

3.3.8 End Users and Output

The RoadLens platform was built to serve multiple end-user types who gained value from the platform's data-based information pertaining to road infrastructure conditions. The system ensured that various end-user groups were able to extract information useful to them based on their needs and level of authority by offering real-time distress information with visualizations easy to interpret, and the ability to command role-specific access levels.

3.3.8.1 Access for Public Users

The RoadLens platform allows public users to access the interactive map and aggregated statistics without logging in. This ensures that any member of the public, as well as commuters and community members, has the ability to stay on top of the relevant road condition and distress locations in their area. Public users rely on the visual representation of distress point when using the map markers, heatmaps, filters by severity or distress type. Public users do not submit reports, nor have access to a deeper level of data, but they can view attempts that are live and specific to the roads surrounding them in a transparent manner. This level of transparency aids in community awareness and contributing to informed travel decisions.

3.3.8.2 Use by Authorities

Government agencies, city planners, and road maintenance organizations are key stakeholders and users of the RoadLens platform for decision-making and determining where should their resources be allocated. Registered users have access to an admin dashboard that provides full visibility, including detailed distress reports, contributor profile information, and issues flagged. Through clustering and severity mapping, Road Lens allows user authorities to identify areas needing the most critical repair work, along with visible maintenance planning. Authorities can also oversee contributions from surveyors, analyze the quality of data from contributors and moderate submissions. This specific use of data supports evidence-based infrastructure management and increases responsiveness to public distress concerning roads.

3.3.8.3 Use by Researchers

RoadLens is utilized by researchers and academic institutions to inform spatial and temporal analyses of the conditions of roadways, patterns of distress, and various socio-environmental factors. The scale and accessibility of the anonymized datasets and geospatial visualizations enable the researcher's examination of relationships between road distress and traffic volume, land use, accidents and other safety issues, and underlying socio and environmental conditions. RoadLens data can be used to develop decisions of functional or formal regionalization in the context of understanding how patterns of transportation disruption may impact urban and regional planning knowledge. As researchers, their outputs can lead to recommendations for new policies, better design and new technologies for the effectiveness of roadway impacts. Therefore, RoadLens is a proven and significant avenue for future research and continual support in the development of sustainable road infrastructure.

3.3.9 Summary of the System Flow

The RoadLens platform had been built as an end-to-end, public participation-enabled system that streamlined the collection, processing, visualization, and dissemination of road distress data. The system's clearly defined workflow ensured a smooth transition from crowd-sourced observations to practical, actionable insights for all stakeholders.

3.3.9.1 Step-by-Step Data Journey

The RoadLens system works linearly and systematically—from the data collection and observation, onwards to output:

1. User Registration and Evaluation: Contributors show interest by completing an evaluation form; only after they are approved, they are able to complete the crowdsourcing survey.
2. Crowdsourced Data Submission: Surveyors record Indo and road distress through a mobile and user-friendly form and include valuable characteristics, images, and geolocation.
3. Data Storage and Processing: Submitted data is securely stored in the Supabase backend, while images are stored externally, with relevant metadata linked in the database.
4. 4. Data moderation: Admins moderate evaluators' applications, moderators can approve surveyors who have submitted the evaluations, and they can also moderate the submissions to ensure that the data is valid.
5. Interactive visualization: The validated data from surveyors, is displayed on interactive maps (using Leaflet.js) with optional layers for filtering, proportion clustering and heat mapping is available to the public user and the admin.
6. Feedback and reports: Contributors and public users can view aggregated statistics, view their submission history and flagged content can be reported.
   It flows well from individual observations into aggregated actionable items.

3.3.9.2 Contribution to Decision-Making and Future Improvements

The organized collection and visualization of road distress data will support evidence-based decisions made by authorities and planners. The quality of the spatially accurate road distress data, in conjunction with RoadLens, will support planning authorities in the prioritization of maintenance needs, as well as the allocation of resources, and support the impact assessment of these planned improvements. The data in RoadLens can also assist in research, policy development, and long-term infrastructure benefits. For example, RoadLens data can be pivotal in influencing funding and remedying significant roadside safety issues. Future development of the system will include automated spatial analytics, further localizing the mobile application with information from municipalities and other levels of government, improving real-time alerts, and enhanced engagement with community groups, all with the overarching goals of improving accuracy and usability. Overall, the flow within this systematic approach develops a collaborative ecosystem for sustainable road management and ongoing improvements.

3.4 Data Collection Using RoadLens

This section provides an account of methodical steps that were taken to acquire real-world data with RoadLens, a participatory GIS-based tool created for crowdsourced monitoring of road distress. This phase had two main objectives: (i) to implement the RoadLens platform as it is designed to be used in practice and evaluate the user experience, and (ii) to collect reliable geospatial and contextual information on road surface conditions across Rajshahi City.

3.4.1 Participant Selection Criteria

In total, 20 participants were selected through purposive sampling to ensure the quality of contributions, based on physical contributions. Selection was based on having digital literacy, having an academic background in areas such as urban planning, civil engineering, or environmental studies, and knowledge of urban mobility in Rajshahi. The participant group consisted of university students (70%), local residents (20%), and civic volunteers (10%). All selected individuals successfully completed the built-in evaluation process of RoadLens, including a knowledge test, image-based classification, and a trial submission.

3.4.2 City-Wide Road Network Assessment

Unlike studies that focus on predefined road segments, this research employed an open spatial approach. Participants were allowed to explore and assess the entire urban road network of Rajshahi City, encompassing primary, secondary, and tertiary roads.

Unlike studies that focus on predefined road segments, this research employed an open spatial approach. Participants were permitted to examine and evaluate the entire urban road network of Rajshahi City, including its primary, secondary and tertiary roads. The group studied one city at a time, collecting distress data across a range of road hierarchies and land uses, such as commercial corridors, residential areas, institutional areas, and peripheral area roads. Participants traveled freely through the road system noting distress points as they encountered them. This provided another representation and geological diversity for the dataset.

3.4.3 Survey Duration and Field Conditions

The survey phase completed over a continuous period of 14 days in June 2025, which was planned to coincide with the early monsoon season. The survey period was deliberately chosen to observe distress development under various types of environmental stress, including rainwater accumulation and drainage failure.

Participants conducted the surveys using mobile devices, accessing the RoadLens web platform directly via browser. Field conditions varied from dry daylight assessments to rainy and overcast conditions. Participants were instructed to perform surveys during multiple times of the day to avoid temporal sampling bias.

3.4.4 Types of Data Collected (Quantitative and Qualitative)

The RoadLens system captured both quantitative and qualitative data. Each contributor-submitted form included the following quantitative attributes:

- Distress Type (e.g., pothole, crack, edge crack)
- Severity Level (low, moderate, high)
- Distress Size
- Traffic Volume
- Road Type
- Drainage Condition
- Accident History
- Adjacent Land Use
- GPS Coordinates
- Image of the Distress
- Timestamp

Qualitative data was collected through an open-ended digital questionnaire administered after the fieldwork. Respondents were asked to consider usability, the issues that arose while submitting, and any thoughts about layout or avatar usability functions.

3.4.5 Sample Characteristics

There were 20 contributors that represented a reasonably balanced demographic and experiences. Most participants were university students in formal technical programs, in addition to public-spirited residents with some experience with mobile surveying. Geographically, the data covered a wide spatial distribution across the entirety of Rajshahi

City. High-density reporting was observed in zones with complex traffic dynamics, poor drainage, or institutional significance. Surveys were performed autonomously by participants navigating the urban grid, reporting distress points via the RoadLens form interface.Data—images, coordinates, and distress metadata—were automatically uploaded to the cloud-hosted Supabase database and image links were stored using the ImgBB API. This phase offered the foundation for the geospatial analysis and testing of the RoadLens tool in actual urban environments.

3.5 Quality Assurance and Validation

In order to ensure the integrity and usability of the data collected in the RoadLens platform, a multi-layer quality assurance plan was established that prioritized the assessment of the spatial and visual correctness of the distress reports collected, the correcting of erroneous submitted responses, and the development of how the system works collectively as a whole based upon the user experience and feedback. This section presents the key quality control measures undertaken to verify the integrity of the dataset, and the operability of the RoadLens tool in the field.

3.5.1 Manual Review of Entries

Each submitted distress entry underwent a systematic manual verification protocol. Admins were able to access RoadLens moderation panel, and there they checked the individual submissions - each submissions contained images, coordinates, and selections for attributes (clear, relevant, and having a known condition). Admins pay particular attention to;

- The consistency of distress types labelled (for example; making sure a pothole is not mistakenly labelled as a crack).
- The congruence between image content and selected severity.
- Logical accuracy across input fields (e.g., avoiding a mismatch such as a large distress area with a "low severity" label).

Submissions failing to meet minimum accuracy thresholds were flagged for revision or removal.

3.5.2 Image and Coordinate Accuracy Checks

Visual content and geospatial metadata were validated to preserve the dataset's spatial integrity. Submitted images were first assessed for clarity, relevance, and format. Images found to be blurred, unrelated to road conditions, or improperly uploaded were excluded.

For spatial accuracy, the device's GPS coordinates (latitude, longitude, and reported accuracy) were recorded during each submission. Using ArcGIS 10.8, we ran a spatial overlay analysis to identify incorrectly geotagged submissions. In particular, we checked for points falling outside road buffers or clustering suspiciously in non-urban zones (e.g., open fields). Erroneous entries were either corrected manually—by cross-referencing EXIF metadata—or deleted if unresolvable.

3.5.3 Feedback-Based Correction

Following data collection, each of the 20 field participants was asked to provide detailed feedback regarding their experience with RoadLens. Open-ended responses and structured evaluation metrics highlighted recurring issues, such as difficulty selecting severity levels. Based on this response, we contacted contributors whose submissions had multiple anomalies, clarifying what was submitted in the multiple instances. In some cases, users were contacted to resubmit the survey after clarifying their distress category or after selecting a different image. This user-based correction process improved the data quality, while reinforcing contributors' investment in the tool.

3.5.4 Removal of Incomplete or Duplicate Entries

The data cleaning was completed using a combination of internal RoadLens tools and ArcGIS spatial analysis. Incomplete submissions (e.g. submissions missing a distress image, GPS data, or important attribute fields) were automatically filtered out. ArcGIS's "Find Identical" and "Delete Identical" tools were used to flag all duplicated entities in the data, especially submissions that had the same coordinates, distress type, and collection date. This was particularly important to ensure that the same submission was not used multiple times to confuse the analysis, caused by poor connectivity from the user's mobile network or confusion on the part of the user.

3.5.5 Functional Testing of the RoadLens Tool

We also carried out several rounds of technical testing to a major part so that the platform was reliable. The technical testing included:

- testing browser compatibility (Chrome, Firefox, mobile browsers)
- latency testing with different internet speeds, including testing over 3G and unreliable WiFi connection
- simulated image uploads with various lighting and environmental conditions.

During the technical testing initiation, we logged all issues (ie image upload delay or gps fetching inconsistency) and addressed them during the development sprint cycle. The evaluation phase also showed that the survey forms worked acceptably well on mobile devices, with very little user training.

3.6 Spatial Intelligence and Visualization

This section focuses on the geospatial and analytical techniques applied to the road distress data harvested from the RoadLens platform. The intention behind this framework of analysis was to turn geotagged field data into not only spatial representations but also portray interrelationships for further infrastructure evaluative work. Spatial processing was performed using ArcGIS 10.8.1 while tabular and statistical computations were done with Microsoft Excel.

3.6.1 Spatial Data Integration and Preparation

Before conducting spatial analysis, geotagged distress data was collected by surveyors. For every distress point, attributes such as type of road, category and severity of distress, drainage quality, volume of traffic, and surrounding land use were noted. These attributes were then imported into ArcGIS where they were spatially joined with the official road shapefile of Rajshahi City. The shapefile contained five categories of roads: Highway, Main Road, Residential Road, Commercial Road, Service Road.

To evaluate data coverage in surveyed locations, a buffer zone of 100 meters was created around each distress point. These buffers were then used to extract road segments that fell within the buffer zone. Using the “Clip” and “Calculate Geometry” functions on ArcGIS enabled computation of total surveyed lengths by road types leading to identification of field data coverage for each road class.

3.6.2 Kernel Density Estimation (KDE) for Distress Intensity Mapping

In order to analyze the spatial distribution of road distress intensity, Kernel Density Estimation (KDE) was used with the distress point layer in ArcGIS 10.8.1. A local spatial influence of 100 meters was set as the search radius. The output from KDE was classified into five levels of density: Very Low, Low, Moderate, High, and Very High using Natural Breaks (Jenks) classification method. This raster surface was later exported for integration into a web-based platform which employed Leaflet.js for visualization thus aiding in decision-making by illuminating areas with high concentration of distress.

3.6.3 Crosstabulation and Chi-Square Statistical Testing

Crosstabulations were conducted to explore categorical relationships among variables including Road Type and Distress Type, Traffic Volume and Repair Priority, Drainage Quality and Distress Severity, and Area Type and Distress Severity. Tabular data summaries that displayed both proportional distributions and frequency counts were produced.

To determine whether the patterns we noticed were just random or if they indicated genuine connections, we examined the statistical relationships between pairs of variables using Pearson's Chi-Square Test. We utilized Excel's built-in statistical tools to conduct these tests, applying a 5% significance level to interpret our findings. To further validate our results, we also incorporated Likelihood Ratio tests.

3.6.4 Hot Spot Analysis

Hot spot analysis is a geo-statistical method of analysis that looks for statistically significant clusters of high or low values in a geographic dataset. In this research project, hot spot analysis will help to identify the areas of the Rajshahi City Road network where participants reported a statistically meaningful concentration of road distress events using RoadLens.

The analysis will use the Getis-Ord Gi* statistic, a very well-known Local Indicator of Spatial Association (LISA), to analyze spatial clustering of distress severity. In contrast to descriptive approaches such as Kernel Density Estimation (KDE) that demonstrate density visually, the Gi* statistic provides inferential evidence regarding whether the spatial patterns that are observed are statistically significant or simply random distributions (Manepalli, 2011; Hazaymeh & Alomari, 2022). The assessment of each road distress point is not done in a vacuum, but against the severity values, of its neighboring spatial locations. The output results categorical z-scores and p-values for each distress feature to classify regions into hot spots (clusters of high severity distress), cold spots (clusters of low severity or minor issues), or non-clustered or significant clustering of either hot or cold spots. If we see a high positive z-score with a low p-value (usually $p < 0.05$), this indicates that we have a significantly clustered hot spot-outlier or area of concentration of severe road distress beyond what could be expected by random chance.

To ensure that the spatial precision of the clustering analysis was consistent with the road network for the study analysis distance between road distress locations, the study used network constrained Gi* analysis. This factor allows for consideration of how the road-network is connected and study clustering based largely on the distance travelled on a network basis, which better mirrors and explains the spatial behaviors of road distress and damage as part of a larger underlying transportation system (Shahzad, 2020). The outcome from this network constrained Gi* analysis was visualized through thematic maps to demonstrate prioritization areas to consider where maintenance could be targeted. These statistically validated hot spots can facilitate actionable intelligence for urban planners and municipal authorities by identifying areas of concentrated and substantial damaged infrastructure for targeted intervention.

Overall, the hot spot analysis provides a basis for linking the crowdsourced data that was the basis of this study, to strategic management of a critical urban infrastructure component, through the data-driven drought analysis and summary of well-established patterns in the spatial behavior of road degradation. The study provides a tool for the objective of integrating GIS-based tools and spatial analysis approaches into participatory public infrastructure monitoring and contributes to a more transparent, responsive, and evidence-based approach to the maintenance of urban infrastructure decisions by helping to pave the way for a more evidence-based maintenance system in Rajshahi City.

3.7 Platform Testing and Data Integrity Checks

System usability and data integrity were evaluated through structured contributor feedback and metadata inspection. After submission, each form entry was reviewed for completeness, accuracy of location coordinates, and valid distress image attachments. Time stamps, GPS precision indicators, and attribute consistency were also checked manually.

User experiences with task flows such as distress submission, map interaction, and dashboard usage were recorded using a post-submission questionnaire. Observed challenges, such as complexity in distress classification or GPS inaccuracy, were documented to inform system improvement.

3.8 Feedback Loop

A structured feedback loop was employed to incorporate user suggestions into future design iterations of RoadLens. Feedback was gathered from open-ended questionnaire fields and categorized into themes: feature improvements, technical enhancements, and support needs.

Suggestions were then evaluated for technical feasibility and user-perceived value. Examples included adding offline submission functionality, simplifying dropdown menus, improving distress definitions, and enabling visual guidance within the platform. Feature ranking was conducted to prioritize implementation within the system's development cycle.

The platform was built on modular and open-source components, allowing flexibility for future updates and extension to other civic infrastructure domains. Continuous improvement based on field insights ensures that the platform remains adaptable, accessible, and user-centered in urban infrastructure monitoring.

Chapter 4:

Analysis & Results

This chapter outlines the spatial and quantitative analyses completed with data from the crowdsourced RoadLens platform. The chapter aims to transform this crowdsourced data set into usable information for assessing and monitoring road infrastructure. The data was collected from people participating in the project in Rajshahi City and consists of the road distress type, severity, size, road classification, traffic volume, drainage condition, accident history, and geolocation attributes. Given the input data, the following analyses were developed to characterize road condition patterns, clustering behavior, and infrastructure susceptibility in the urban road network.

4.1 Data Coverage

The first step of this analysis was to understand the spatial extent and representativeness of the data collected. To do this, we measured how much of Rajshahi City's Road network was covered by surveyors, and to what extent different road types were included in the study sample.

To evaluate the reach of data collection in this study, we calculated how much of the existing road network in Rajshahi City was effectively assessed by contributors. The city's road network shapefile, classified into five types—Highway, Main Road, Residential Road, Commercial Road, and Service Road—was used to determine total available infrastructure for analysis. The length of each road category was computed using ArcGIS 10.8.1 and converted from meters to kilometers for better readability.

In parallel, a 100-meter buffer was applied around each geotagged distress point to represent its potential area of influence. The union of these buffers was used to clip the road network, isolating segments that fall within the buffer zone and can thus be considered surveyed. Using the "Clip" and "Calculate Geometry" tools in ArcGIS, the lengths of the road segments within the buffered areas were extracted and summarized by category.

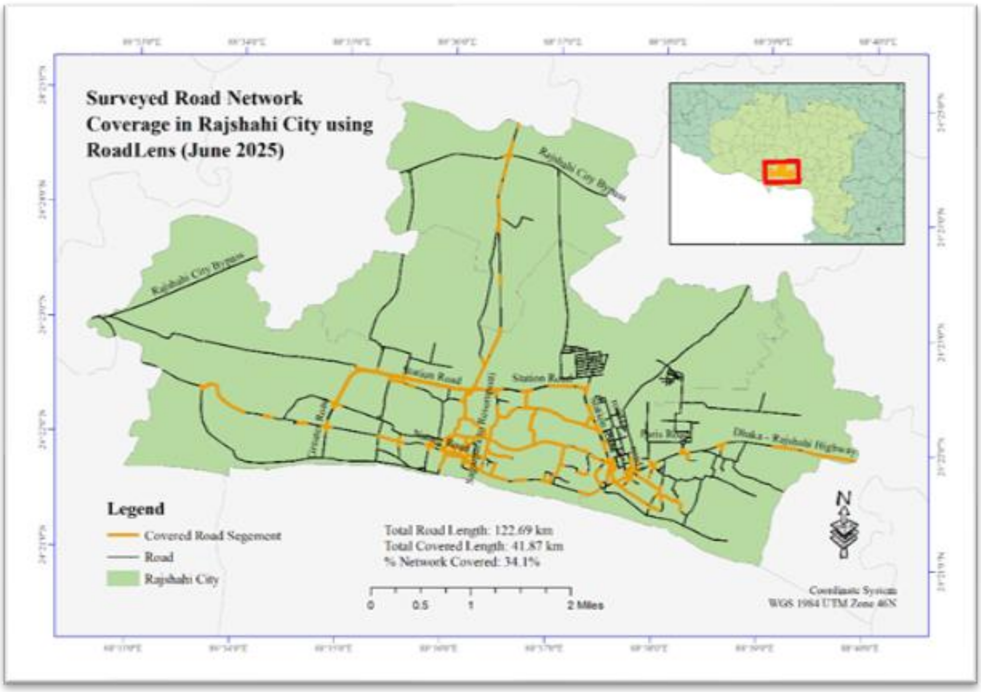
The results of this analysis are shown in Table 2, which compares the total length of each road type with the length that was actually covered by the contributors. The table also includes the percentage of coverage to reflect how well each type of road was assessed.

Table 2: Road Network Coverage by Surveyors (June 2025)

Road Type	Total Length (km)	Covered Length (km)	Percentage Covered (%)
Highway	42.29	21.62	51.1%
Main Road	14.01	8.94	63.8%
Residential Road	52.68	5.59	10.6%
Commercial Road	9.41	3.87	41.1%
Service Road	4.30	1.85	43.0%
Total	122.69	41.87	34.1%

Source: Authors' Preparation, 2025

Approximately 34.1% of the total road network was recorded during the data collection phases, as shown in Table 2. The most coverage was provided by main roads (63.8%) and highways (51.1%). It is also clear indicator a bias in the sampling toward routes with high-accessibility. The least amount of coverage was for residential roads (10.6%), which we assume can be attributed to limited access to contributors intended for that area, timing, or their unfamiliarity with how to contribute in that area.



Source: Authors' Preparation, 2025

Figure 22 : Mapped Survey Coverage Based on 100m Buffers of Distress Points

Figure 22 provides a spatial depiction of our assessment, and in it are the surveyed portions of the road networks shown in red, clearly identifying which segments we effectively processed in the crowdsourced collection of data.

This spatial overview of data coverage informs the subsequent analyses in this chapter on social acceptance and accessibility for public transport in Rajshahi. It ensures that interpretations of clustering tendencies, frequency of distress, and infrastructure gaps are anchored to specific surveyor activity extents over the many roads that comprise and connect Rajshahi.

4.2 Frequency Analysis of Road Distress Types

The goal of this section is to assess the frequency and type of road distress across the various classes of roads in the city of Rajshahi. Assessing the frequency will help state which classes of roads are called structural failure more often and which types of distress are reported more frequently. This is beneficial for establishing maintenance prioritization and reinforcing data-based monitoring methods as part of participatory infrastructure governance.

Using the RoadLens platform, contributors reported 388 distress points across Rajshahi City. The distress points are automatically assigned to both a road type and a distress type upon submission. Road distress types included Edge Crack, Narrow Crack, Patching, Pothole, Raveling, and Wide Crack. Table 3 shows the frequency distribution of distress, organized by road type.

Table 3: Frequency of Distress Types by Road Category

			Distress Type						Total
			Edge Crack	Narrow Crack	Patching	Pothole	Raveling	Wide Crack	
Road Type	Highway	Count	3	1	29	46	8	0	87
		% within Road Type	3.4%	1.1%	33.3 %	52.9 %	9.2 %	0.0 %	100.0 %
		% within Distress Type	6.1%	12.5 %	24.2 %	38.7 %	9.0 %	0.0 %	22.4 %
	Main Road	Count	29	4	64	38	32	2	169
		% within Road Type	17.2 %	2.4%	37.9 %	22.5 %	18.9 %	1.2 %	100.0 %
		% within Distress Type	59.2 %	50.0 %	53.3 %	31.9 %	36.0 %	66.7 %	43.6 %
		Count	4	1	10	16	34	0	65

	Market/Commercial Road	% within Road Type	6.2%	1.5%	15.4%	24.6%	52.3%	0.0%	100.0%
		% within Distress Type	8.2%	12.5%	8.3%	13.4%	38.2%	0.0%	16.8%
	Residential Road	Count	10	2	14	15	13	1	55
		% within Road Type	18.2%	3.6%	25.5%	27.3%	23.6%	1.8%	100.0%
		% within Distress Type	20.4%	25.0%	11.7%	12.6%	14.6%	33.3%	14.2%
	Service/Private Road	Count	3	0	3	4	2	0	12
		% within Road Type	25.0%	0.0%	25.0%	33.3%	16.7%	0.0%	100.0%
		% within Distress Type	6.1%	0.0%	2.5%	3.4%	2.2%	0.0%	3.1%
Total		Count	49	8	120	119	89	3	388
		% within road Type	12.6%	2.1%	30.9%	30.7%	22.9%	0.8%	100.0%
		% within Distress Type	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

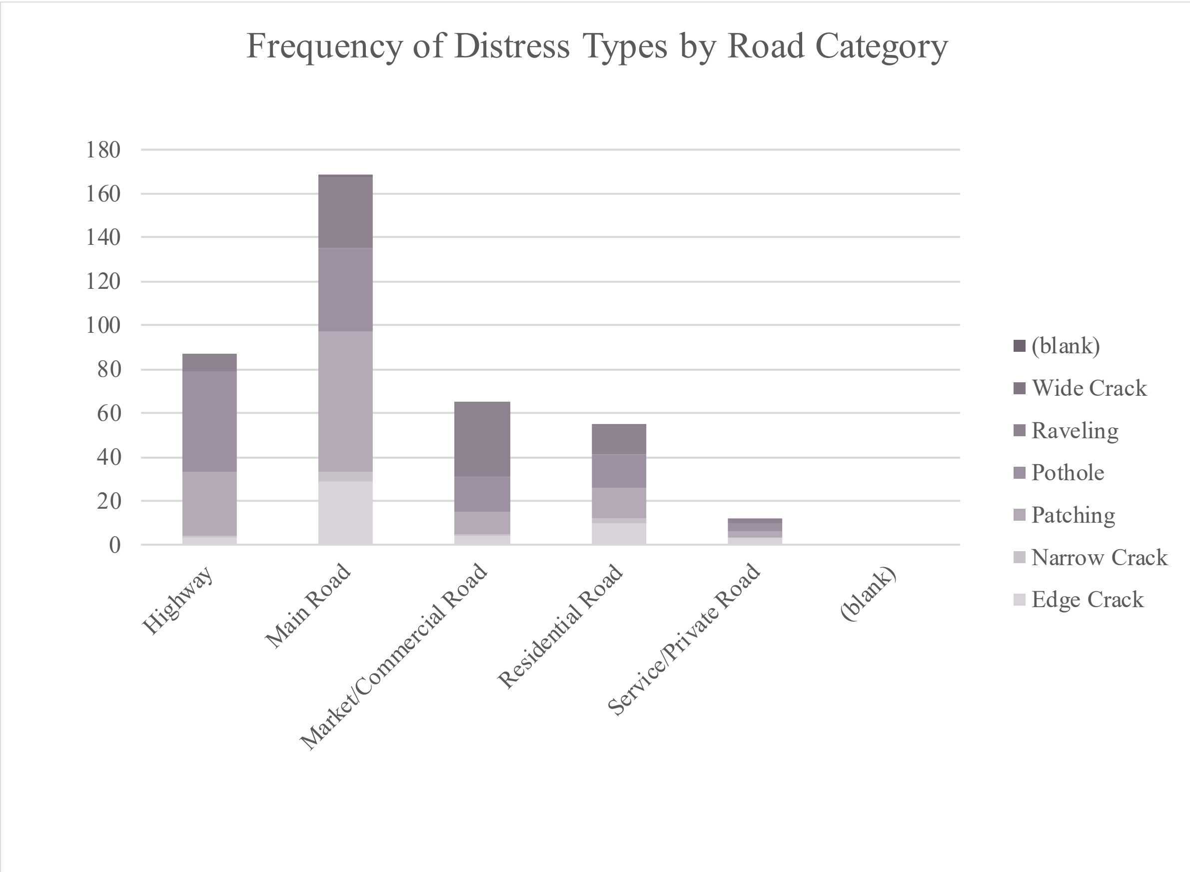
Source: Authors' Preparation, 2025

The detailed examination of the table highlights Main Roads reporting the uppermost distress count at 169 points (or 43.6% of the total report). Principal reasons for scourging in Main Roads were Patching (64) and Edge Cracks (29). This demonstrates the heavy axial loads and repetitive wear which Main Roads receive making them very vulnerable to fatigue on their surfaces and instability of their subgrade condition. Note, the traffic conditions on Main Roads is systemic, frequent, heavy and stagnant causing odd environmental situations compared to other types of roads.

Highway identification conditions typically express the road only used to segment vehicle activity and transport. Highways reported a total of 87 points of distress (with Potholes (46) and Patching (29) showing frequency). This disclosed 2 report types accounted for 86.2% of the total distress candidate reports aggregates within the highway corridor. On Market or Commercial Roads, the most dominant distress type was Raveling (34), which may be contributory due to surface wear on each vehicle material segregating through time, surface wear as the wherein the surface is used due to pedestrian activity, vehicle turning to exit, and maintenance practices which are substandard. Displaying indications of localized stresses and poorly adhered surfaces, particularly, commercially relied upon spaces. Residential Roads, while having a lower traffic load, still recorded 55 total distress points, with

Potholes (15) and Patching (14) being the most common. This suggests issues related to unregulated water runoff or lack of structural layering in low-volume roads. Service and Private Roads which are usually internal roads accessible to some institutions or facilities have very little distress in total (12). There is probably less distress in this group because of reduced traffic, smaller road surfaces, or underreporting, as surveyors could not assess this road type due to limited access.

The frequency analysis shows that the intensity and type of road distress is strongly correlated with the functional classification of roads. Patching (120) and Potholes (119) accounted for 61.3% of distress cases overall, which are the usual threats to road serviceability in Rajshahi City. This trend is also represented visually in Figure 23, plotting the total counts for each distress type by road category.



Source: Authors' Preparation, 2025

Figure 23: Frequency of Distress Types by Road Category

4.3 Relationship Between Road Type and Distress Type

After the frequency analysis, this section will assess if there is a statistically significant association between the type of road and the type of distress observed. The previous section showed how often specific distress types occurred on all the road categories combined and whether distress types showed any sort of distribution based on road category, while this section will attempt to demonstrate whether or not such distributions are generally statistically associated with road function, or if they could just occur randomly.cTo determine the relationship, a crosstabulation analysis was performed on the variables Road Type and Distress Type. To statistically test the associations observed, a Pearson Chi-Square test was also performed, as seen in the associated Table 4.

Table 4: Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	77.578[a]	20	.000
Likelihood Ratio	75.503	20	.000
N of Valid Cases	388		

Source: Authors' Preparation, 2025

The analysis produced a Chi-Square value of 77.578 (df=20, $p<.001$), suggesting a robust and statistically meaningful association between Road Type and Distress Type. The findings were corroborated by the Likelihood Ratio Test which produced $\chi^2 = 75.503$, $p<.001$ and established that the relationship was worthwhile. In effect, the analyses indicated there was not a random distribution of Distress type among the categories of Roads, but that they were significantly impacted by influences associated with road use, construction quality, and environmental exposure.

To summarize, the analysis here has validated a substantial area of function-specific road maintenance. All types of roads behaved differently regarding the types of distress they are associated with and required different adaptive signals to intervene with road maintenance. However, Rd is the most distressed road type, in terms of frequency and variety of reports, which further identifies it as a structurally and operationally distressed road type. The implication for road asset management in Rajshahi City is that maintenance planning and efficient allocation of resources will need to reflect the largest strain on the road assets, the corridors of the city already firmly allocated to several classes of entities, while establishing the patterns of stressors and unique vulnerabilities of other road types.

4.4 Relationship Between Traffic Volume and Repair Priority

To find whether traffic volume influence prioritization of urgency when responding to a road distress case, we did a crosstabulation analysis with 388-point records of distresses (as per the table). Traffic Volume was categorized at three levels - Low (1), Medium (2) and High (3) - and compared to Repair Priority levels (also three categories: 1 (High), 2 (Medium), 3 (Low).

Table 5: Traffic Volume & Repair Priority Crosstabulation

			Repair_Priority			Total
			1	2	3	
Traffic_Volume	3 (High)	Count	82	45	35	162
		% within Traffic_Volume	50.6%	27.8%	21.6%	100.0%
		% within Repair_Priority	39.6%	41.7%	47.9%	41.8%
	1 (Low)	Count	2	4	1	7
		% within Traffic_Volume	28.6%	57.1%	14.3%	100.0%
		% within Repair_Priority	1.0%	3.7%	1.4%	1.8%
	2(Medium)	Count	123	59	37	219
		% within Traffic_Volume	56.2%	26.9%	16.9%	100.0%
		% within Repair_Priority	59.4%	54.6%	50.7%	56.4%
Total		Count	207	108	73	388
		% within Traffic_Volume	53.4%	27.8%	18.8%	100.0%
		% within Repair_Priority	100.0%	100.0%	100.0%	100.0%

Source: Authors' Preparation, 2025

Table 6: Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	4.756[a]	4	.313
Likelihood Ratio	4.403	4	.354
N of Valid Cases	388		

Source: Authors' Preparation, 2025

There were 219 cases of roads with medium traffic volume, which was the greatest number of cases reported, making up 56.4% of the total. Of this group there were 219 cases reported as High Priority, and 58.0% were reported as High Priority repair; 20.2% of them were assigned Medium Priority and 13.4% of them were assigned Low Priority. This later finding suggests that the roads at the moderate level of traffic were still in significant distressed conditions that required repair action, in consideration of the fact that in more than one of two cases, the situation warrants urgency in repair action.

Around 162 cases of investigated roads had high traffic volume. Among these units, 50.6% of the cases were classified as High priority, 27.8% were classified as Medium Priority, and 21.6% were Low Priority. While not as great a share in terms of range as the comparable group of medium traffic volume, the share of cases at the High level of traffic volume still contributed significantly to urgent repair needs, representing 39.6% of all cases in the dataset assigned High Priority for repair.

In contrast, low traffic volume roads accounted for only 7 reports, which is just 1.8% of the total. Of these, 57.1% were assigned Medium Priority, and only 28.6% were classified as High Priority. This small sample size may limit broader generalizations, but the trend indicates that roads with less vehicle flow are less likely to be assigned high urgency for repairs. From a descriptive standpoint, both medium and high-traffic roads are more likely to receive High Priority repair classifications compared to low-traffic roads. This could be due to the higher stress levels, wear, and visibility associated with busier corridors. However, despite these observable patterns, the Pearson Chi-Square test yielded a value of 4.756 (df = 4, p = .313) and the Likelihood Ratio test gave 4.403 (p = .354). Both p-values exceed the conventional 0.05 threshold, indicating no statistically significant association between traffic volume and repair priority in this dataset.

This result means while high and medium-volume roads seem to receive action, in practical terms, the differences are likely not sufficiently different enough to meet a level of statistical reliability across the board. Other factors related to determining priority such as severity, type of road, land use or discretion may be more influential.

4.5 The Relationship Between Drainage Quality and Distress Severity

In this section the link will be examined between conditions of drainage infrastructures and the severities of distress levels, measured across all segments in Rajshahi City. One of the most critical elements influencing the life of the pavement is the quality of drainage and examination will be done here to check if poor drainage is contributing significantly to the built-up severity to distress. To check the correlation, a crosstabulation description and chi-square test results have been created, using data as collected through RoadLens.

Table 7: Cross Tabulation Between Drainage Quality and Distress Severity

			Distress Severity			Total
			High	Low	Medium	
Drainage Quality	Good	Count	8	34	9	51
		% within Drainage Quality	15.7%	66.7%	17.6%	100.0%
		% within Distress Severity	11.0%	16.4%	8.3%	13.1%
	Moderate	Count	31	138	60	229
		% within Drainage Quality	13.5%	60.3%	26.2%	100.0%
		% within Distress Severity	42.5%	66.7%	55.6%	59.0%
	Poor	Count	34	35	39	108
		% within Drainage Quality	31.5%	32.4%	36.1%	100.0%
		% within Distress Severity	46.6%	16.9%	36.1%	27.8%
Total		Count	73	207	108	388
		% within Drainage Quality	18.8%	53.4%	27.8%	100.0%
		% within Distress Severity	100.0%	100.0%	100.0%	100.0%

Source: Authors' Preparation, 2025

The analysis provided in Table 7 gives the level of distress (Low, Medium, and High) as it relates to three drainage quality levels – Good, Moderate, and Poor. As previously discussed, for roads deemed to have "Good" drainage, the number of Low severity distress points represented 66.7%, while cases classified as High only accounted for 15.7% of the total. This provides a circumstantial example of drainage aiding to minimize the risk of advanced deterioration of pavement.

For road segments that had Moderate drainage, the representation of Low severity distress dropped to 60.3% and the proportions of the medium combined with high severity distress both increased to 26.2% and 13.5% respectively. This indicates a further trend of distress and condition deterioration with reduced drainage quality.

A very different pattern was reported for segments characterized by Poor drainage quality. In this data set, about 31.5% of the cases were categorized as High severity - double the number of roads exhibiting good drainage classification. Medium and Low severity cases were nearly equally distributed (36.1% and 32.4%, respectively), suggesting a progressing pattern of distress in poorly drained zones. Notably, 46.6% of all High severity cases in the entire dataset originated from poorly drained road sections, compared to just 11.0% from well-drained areas. To assess statistical significance, a Pearson Chi-Square Test was performed as viewed in the table 8. The results ($\chi^2 = 30.269$, df = 4, $p < 0.001$) confirmed a highly significant association between drainage quality and distress severity at the 95% confidence level. The Likelihood Ratio test ($\chi^2 = 30.405$) corroborated these findings, strengthening the assertion of drainage as a primary determinant of road surface conditions.

Table 8: Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	30.269[a]	4	.000
Likelihood Ratio	30.405	4	.000
N of Valid Cases	388		

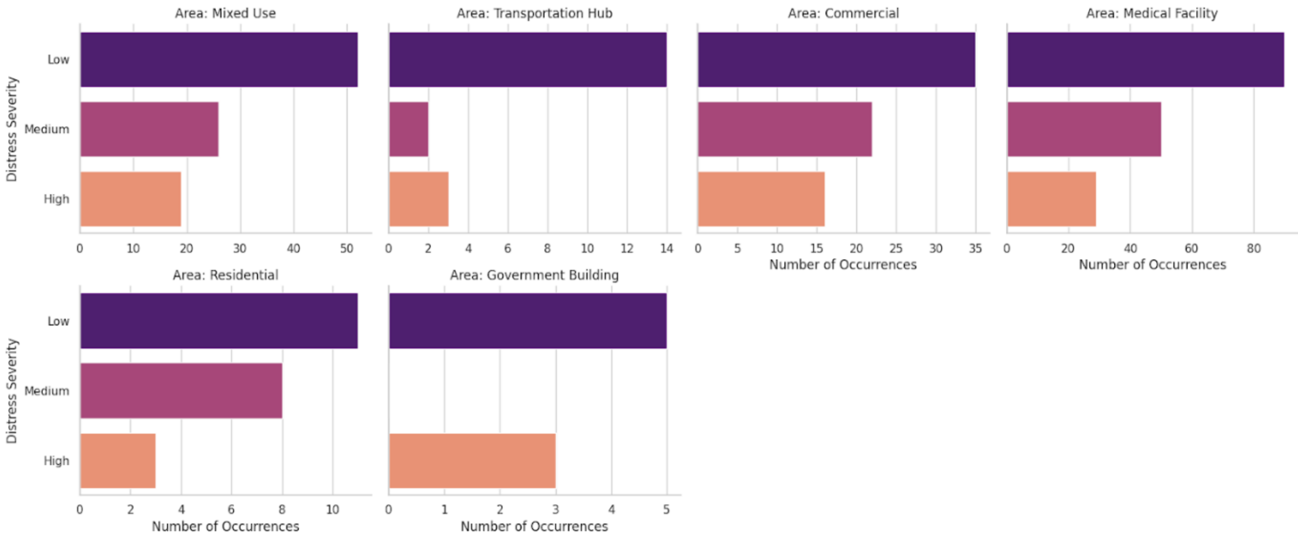
Source: Authors' Preparation, 2025

This highlights the importance of using drainage quality assessment data in the maintenance planning of infrastructure. The link between inadequate drainage and high-severity pavement disabilities can be instrumental to help direct the design of preventive measures that will ultimately help to prioritize drainage rehabilitation and surface maintenance. When considering a context such as Rajshahi City where monsoon induced stresses must be held firmly in mind, any delay in addressing drainage systems will inevitably lead to pavement deterioration regardless of its origins

4.6 Analysis of Distress Severity by Adjacent Area Type

This section investigates whether road distress severity differs based on the type of adjacent land use, using data collected from the RoadLens platform. The research question is to determine if the surrounding land use's functional nature, (commercial, institutional, or residential) has a significant effect on the pavement condition. This is important given the potential implications for the development of location-sensitive maintenance strategies and in making inspection timelines.

Before discussing the data, Figure 4.5 is a faceted bar chart that visually communicates the amount of road distress severity (Low, Medium, and High) by adjacent land use. The facets in the figure 24 represent the different land use types (Commercial, Educational, Residential, Mixed-use, and Transportation Hubs), and each facet's segmented bars then represent the proportion of road distress points recorded for that respective level of severity.



Source: Authors' Preparation, 2025

Figure 24: Relationship Between Distress Severity by Adjacent Area Type

Observing patterns like the geographic concentration of high-severity reports within functional zones and comparatively lower severity in others help to appreciate how land use context may affect road condition.

High Severity in Functionally Intensive Zones

The analysis showed that zones categorized as Commercial, Transportation, and Mixed-Use had greater amounts of High-severity distress points than the functional designation indicated. These zones are also inherently subject to greater traffic flows, including frequent stopping and turning choices made for commercially-related purposes, as well as the movement of heavy-duty vehicles. All of these factors in combination contributed to real structural stress from the different levels and types of use and intensified wear in a relatively short period of time. In instances, Commercial corridors located adjacent to markets, and logistics depots, recorded some of the highest severity scores in the dataset.

Given their variable mobility role for daily commerce, active monitoring as well as selective periodic maintenance, in a systematic way, should be integrated for those functional zones. The results indicate that stratifying functional land use as a weight in the decision framework for prioritizing the repair and maintenance for roads and streets is warranted.

Severity Around Medical and Educational Facilities

Roads positioned near Medical and Educational institutions showed moderate to high distress severity throughout the observed area. These sites need constant access since patients and students form important groups who depend on uninterrupted movement. The combination of severe road damage near these facilities creates both safety hazards and questions about emergency service accessibility and regular service access. The government must treat it as an essential public service to focus on maintenance operations specifically in these zones.

Lower Severity in Residential Areas

By contrast, roads adjoining Residential areas generally exhibited Low to Medium levels of distress severity. This may reflect the influence of several mitigating factors, such as lighter vehicle loads, reduced traffic frequency, and potentially more localized maintenance efforts. The data suggests that while residential zones are not immune to surface deterioration, their distress patterns are less critical compared to high-demand zones.

The spatial correlation between adjacent land use and distress severity confirms the functional dependency of road wear. Roads bordering high-demand destinations are more prone to severe damage.

4.6 Spatial Intensity Mapping of Road Distress Using Kernel Density Estimation

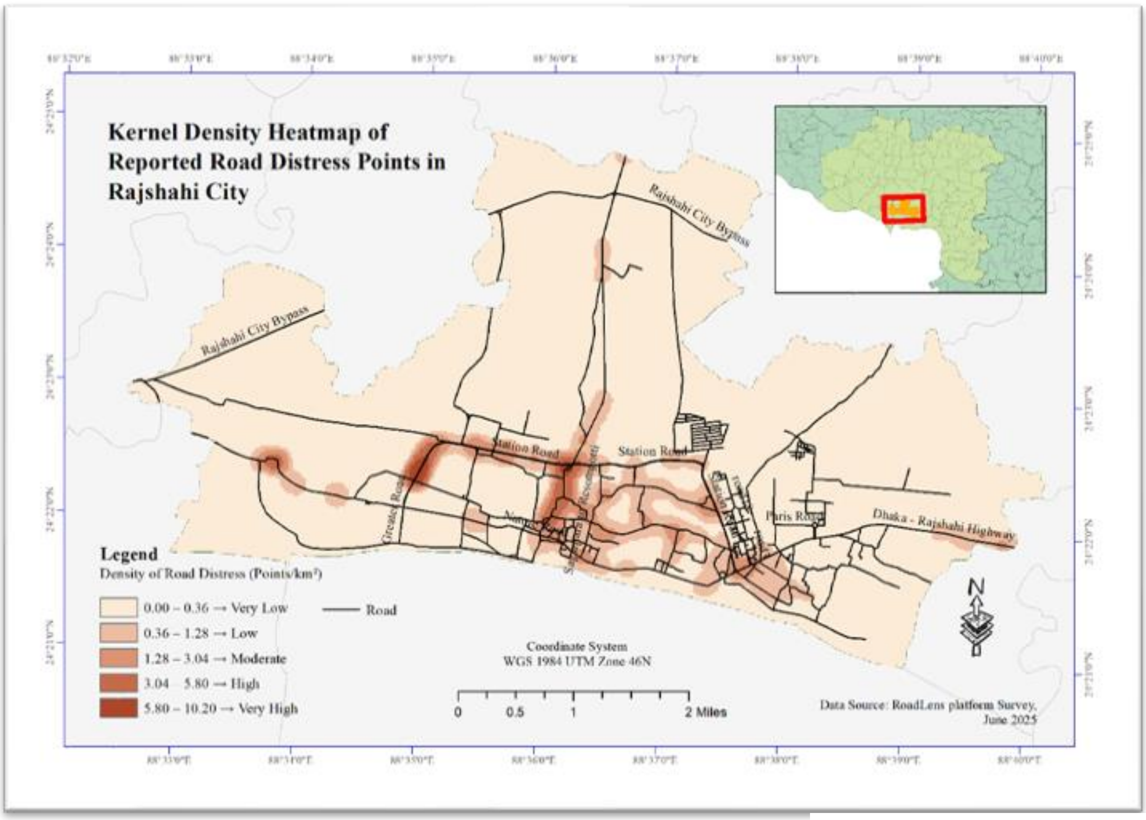
To analyze the spatial congestion and distribution of road distress events across Rajshahi City, a heatmap was developed in ArcGIS 10.8.1 using Kernel Density Estimation (KDE). This geospatial approach allows for the conversion of the distress points to a surface that is continuous, where spatial intensity can be visualized, providing the ability to ascertain urban districts which are at elevated risk of road degradation and urgent need for maintenance. The KDE was based on 388 geotagged distress points collected through RoadLens over a one-month period (June 2025).

For each distress point, regardless of distress type or severity, a unit occurrence was counted. The KDE used a search radius of 100 meters to smoothed the density surface, which approximated the relative concentration of the reports concentrated to local areas. The output raster was categorized into five density classes using the Natural Breaks (Jenks) method to segment the surface into meaningful intervals:

- Very Low Density
- Low Density
- Moderate Density
- High Density
- Very High Density

These categories were visually represented with a color gradient ranging from pale beige (low intensity) to dark reddish-brown (high intensity), with darker zones indicating higher concentrations of distress.

The spatial investigation uncovered a few high-density clusters that aligned with known high-use and commercially active areas within Rajshahi City. The largest identified cluster of distress points was located along the Station Road arterial corridor, encompassing part of Shaheb Bazar and continuing along Natore Road. These areas demonstrated high levels of constant vehicular and pedestrian movement, informal activities, and frequent lack of maintenance as shown in the below figure 25.



Source: Authors' Preparation, 2025

Figure 25: Spatial Intensity Mapping of Road Distress Using Kernel Density Estimation

One other identified hotspot along with Station Road was on the Dhaka-Rajshahi Highway on the east side of Rajshahi City, especially at the intersection with Paris Road and nearby service lanes. The high incidence of potholes and patching complaints is somewhat expected for a primary truck and intercity bus corridor. The road locations in and around Medical Mor and portions of the Rajshahi City Bypass are also identified as high-density clusters with respect to a sample of the road network in the municipality due to poor drainage, corner turning with buses, and location on the edge of the road.

A contrasting situation can be noted in the peripheral and semi-urban territories (e.g., northwestern fringe and eastern rural bands of the city) which had sporadic distributions of distress. In these locations, the land use is primarily residential or agricultural and the road is either less intense and/or did not have enough coverage by contributors, based on the data coverage analysis.

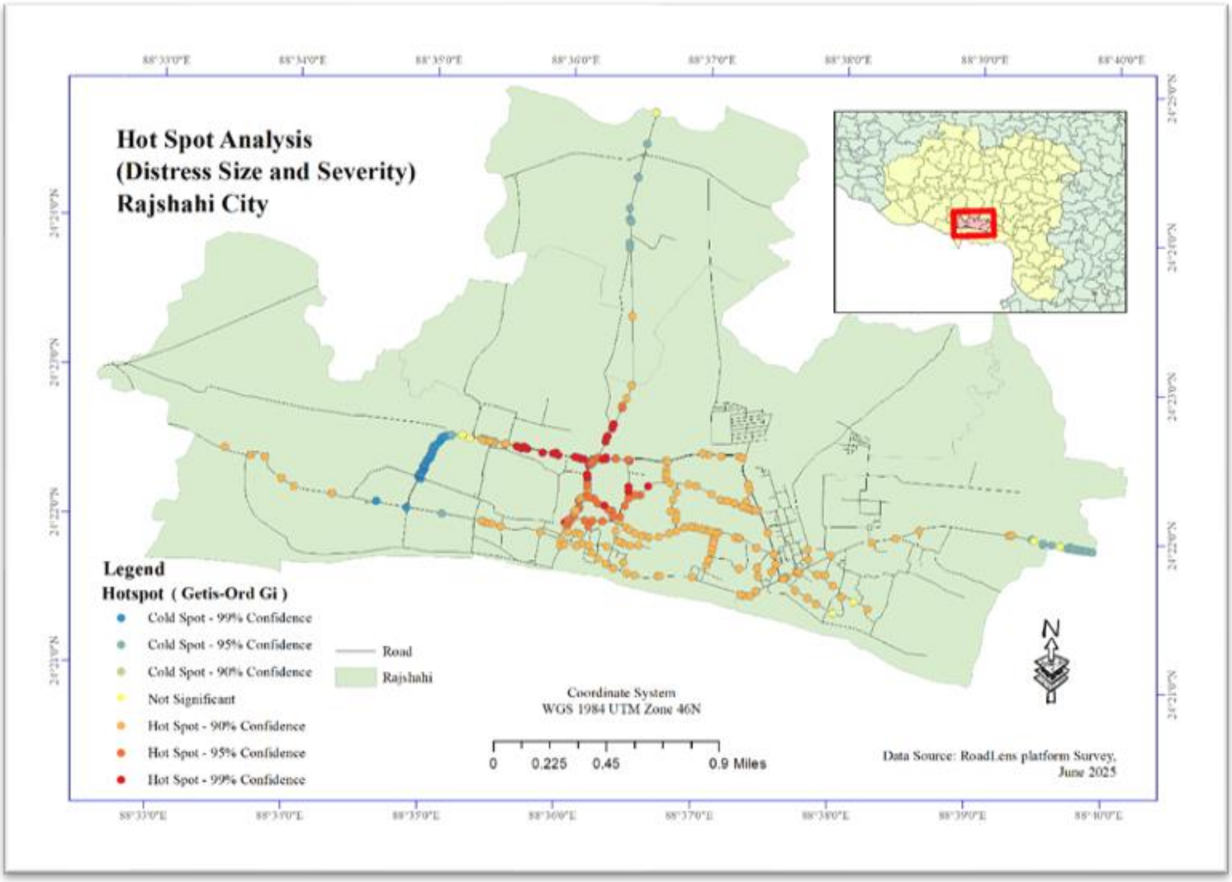
The kernel density heat map gives a useful visual perception of where the repair and monitoring resources should be directed to and reflects well the historical analysis in the frequency analysis component, where road types with high use, primarily main roads and highways, reported the highest level of distress.

A strong visual understanding of where maintenance and monitoring efforts should be concentrated is offered by the kernel density heatmap. Additionally, it is consistent with earlier frequency analysis results that showed higher levels of discomfort on widely traveled route categories, such as main roads and highways.

4.7 Hot Spot Analysis of Distress Size and Severity (Getis-Ord Gi*)

To identify statistically significant spatial clusters of road distress incidents within Rajshahi City, a Hot Spot Analysis was conducted using the Getis-Ord Gi* statistic available in ArcGIS 10.8.1. Unlike simple density-based visualizations such as Kernel Density Estimation (KDE), the Gi* method enables inferential spatial statistics by assessing each feature's value in relation to its spatial neighbors. This allows you to identify statistically significant clusters of distress by size and severity, or distress level, which are the two variables that most need to be prioritized for assets in need of maintenance.

The Getis-Ord Gi* analysis produces z-scores and p-values for each point feature which indicates whether the clustering of large and severe distress is higher than normal when considering expected random spatial distribution. The results produce clusters, which can be defined as hot spots (areas with a significant concentration of high values), cold spots (clusters of significantly low values), or neutral zones (areas with no statistically significant clusters). This can be illustrated in Figure 26 where the output relates to the hot and cold spots observed on the Rajshahi road network, classified at three confidence levels: 90%, 95%, and 99%.



Source: Authors' Preparation, 2025

Figure 26: Hot Spot Analysis

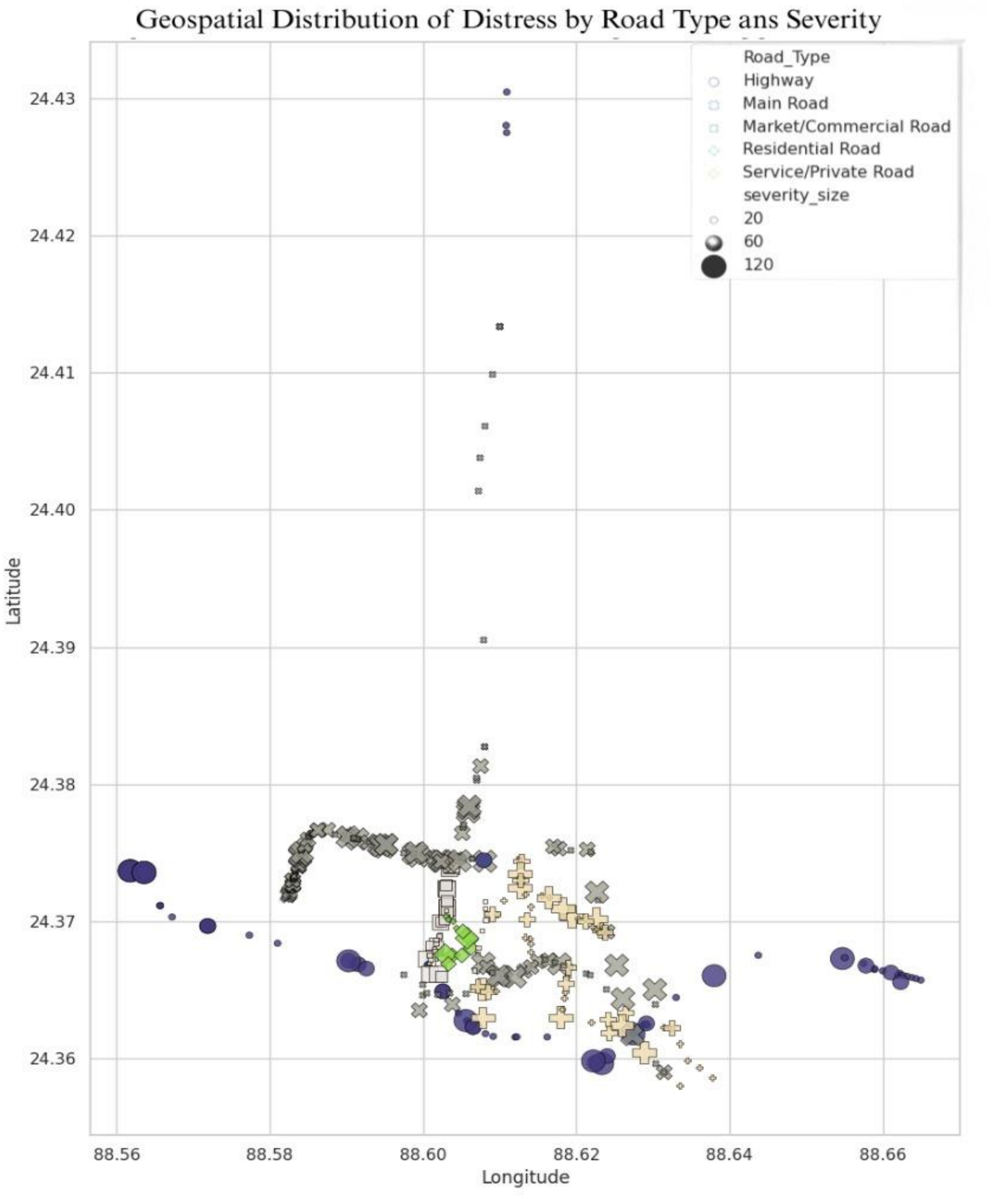
4.7 Geospatial Distribution by Road Type and Distress Severity

In this section, we examine the spatial characteristics of distress distribution across different road types within Rajshahi City, as recorded through the RoadLens platform. The primary objective is to understand whether distress severity is influenced by the functional classification of the road and its geospatial context. Using a multivariable GIS visualization, this analysis synthesizes four core variables—geographical coordinates, road type, distress severity, and spatial clustering—to develop an integrated understanding of how distress events are dispersed across the urban road network.

To perform this analysis, all geotagged road distress points collected by contributors were mapped in ArcGIS using their recorded latitude and longitude. Each point was attributed with its corresponding road classification and assigned a severity level (Low, Medium, High) based on field observations at the time of data entry.

4.7.1 Visual Encoding and Symbolization

In the geospatial output (see Figure 27), different symbol shapes and colors were applied to represent road types. Highways were denoted by purple X-shaped symbols, Main Roads by green circles, and additional road types such as Residential and Service Roads by other symbol and color combinations. This encoding was done to visually distinguish distress points by road classification and allow rapid interpretation of spatial patterns.



Source: Authors' Preparation, 2025

Figure 27: Geospatial Distribution of Distress by Road Type and Severity

Distress severity was encoded through the size of each symbol, with larger symbols representing High severity, medium-sized symbols for Moderate severity, and smaller symbols for Low severity cases. This layered visualization technique made it possible to identify both clusters of distress and the varying intensity levels associated with different functional areas of the road network.

4.7.2 Observations and Patterns

From the spatial distribution, two major clusters of distress events were identified:

1. Urban Core Cluster: The most prominent cluster is concentrated within the commercial and mixed-use zones of Rajdhani's urban core, where the volume of distress reports is highest. However, the majority of these cases fall under Low or Medium severity categories. This suggests frequent but less intense damage, potentially caused by repeated light to medium vehicular use, informal encroachment, and lack of routine surface maintenance.

2. Highway Corridor Cluster: A linear cluster was observed along the Dhaka–Rajshahi highway corridor. Although the number of recorded points is lower than in urban zones, the proportion of High severity cases is significantly greater. This pattern may be attributed to the heavy vehicular load, including trucks and buses, as well as the prolonged absence of resurfacing or preventive maintenance.

These results highlight a spatial dichotomy: urban areas show higher frequency but lower severity, whereas highways display lower frequency but higher severity. This aligns with theoretical expectations in transportation planning and urban infrastructure studies, where functional road type is often correlated with distinct stress profiles and deterioration trajectories (Scolamiero et al., 2025).

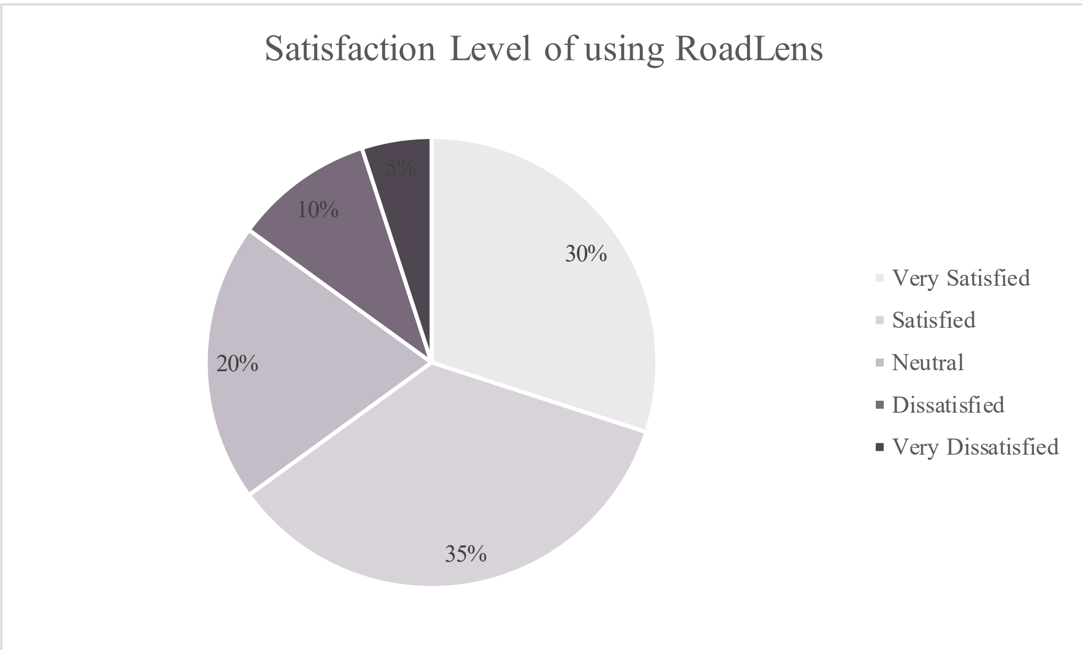
4.7.3 Analytical Implications

The map visualization enables city authorities and planners to spatially identify priority intervention zones. Urban roads, due to their high usage and broad coverage, require distributed maintenance strategies, focusing on resolving frequently occurring moderate damages. Conversely, highway segments may benefit from intensive, less frequent maintenance cycles aimed at preempting high-severity failures.

Furthermore, this spatially disaggregated view supports the development of functional prioritization frameworks—allowing planners to base decisions not only on the presence of damage but also on the criticality of the road type and functional land use context. Integrating such visual data into urban monitoring systems ensures more equitable and effective infrastructure management, especially in resource-constrained cities like Rajshahi.

4.8 Contributor Satisfaction Level

To assess user perception regarding the overall experience of interacting with the RoadLens system, a direct feedback question was incorporated in the post-survey questionnaire. Participants (n=20) were asked to rate their overall experience with the tool using five standard response categories: *Very Satisfied*, *Satisfied*, *Neutral*, *Dissatisfied*, and *Very Dissatisfied*.



Source: Authors' Preparation, 2025

Figure 28: Satisfaction Level of using RoadLens

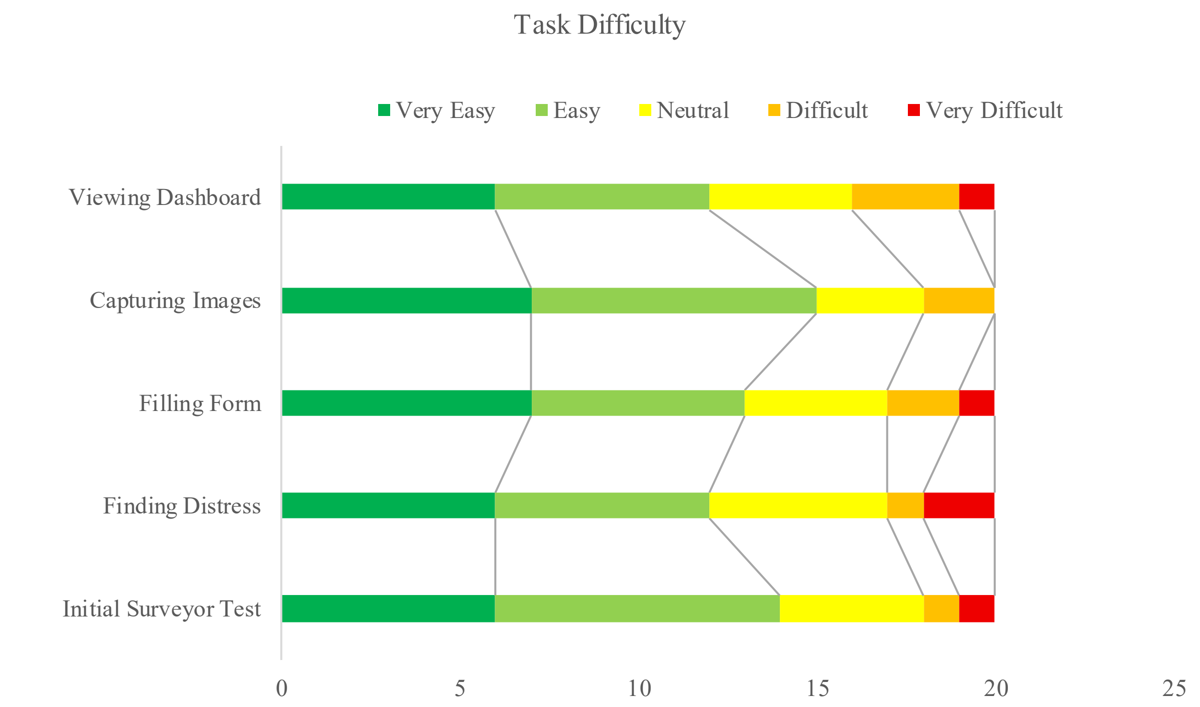
As shown in the figure 28, the majority of users (65%) rated their experience as either *Satisfied* or *Very Satisfied*. This positive reception indicates the platform's general acceptance in terms of usability, functionality, and relevance to task requirements. However, a notable portion (15%) expressed dissatisfaction, which underlines the importance of further iterative improvements to enhance accessibility and technical performance.

Neutral responses (20%) suggest that some users encountered neither critical flaws nor outstanding ease of use—potentially linked to a lack of in-depth familiarity with the platform or mixed feelings about performance stability.

In summary, this analysis confirms that while RoadLens received a predominantly favorable response from early users, there remains a subset of users whose expectations were unmet. This insight is valuable for planning future design revisions and better onboarding strategies.

4.9 Task Difficulty Ranking Analysis

Understanding the usability of individual components of RoadLens is crucial for improving task flows and reducing user frustration. In the post-survey feedback form, participants were asked to rate five core interactions of the platform using categorical difficulty levels (*Very Easy*, *Easy*, *Neutral*, *Difficult*, *Very Difficult*). Viewing Results via Dashboard



	Initial Surveyor Test	Finding Distress	Filling Form	Capturing Images	Viewing Dashboard
Very Easy	6	6	7	7	6
Easy	8	6	6	8	6
Neutral	4	5	4	3	4
Difficult	1	1	2	2	3
Very Difficult	1	2	1	0	1

Source: Authors' Preparation, 2025

Figure 29: Task Difficulty Stacked Bar Analysis

The aggregated responses were then further manipulated into a cross-tabulated table to determine the difficulty level of task-specific task items, which were subsequently visualized in the form of a stacked bar chart (see Figure 29). The participants rated the Initial Surveyor Test as Easy or Very Easy by 14 out of the 20 participants (70%), indicating that the preliminary instructions were very clear and test design was very easy comprehensible. Subsequently, the form filling and image capturing tasks were also determined to be manageable for most participants. Conversely, the "Finding Distress" task and "Viewing Dashboard" were rated with somewhat of a more mixed bag, with 4 out of 20 participants stating the tasks were Difficult or Very Difficult. Qualitative feedback was received indicating that some users struggled with discerning edge cases to distinguish distress types (i.e. raveling & cracking), as well as understanding spatial map space and layout.

The results from this section indicate that there were aspects of interface and main functionalities of the platform considered, that were intuitively designed, while there were other functions considered that need improvement to increase overall experience (i.e. visual recognition and spatial navigation).

4.10 Feature Preference and Qualitative Feedback Analysis

To enrich the platform evaluation with user-centered insights, a qualitative feedback analysis was performed based on open-ended responses collected from 20 contributors. The purpose was to extract actionable suggestions to improve both the technical robustness and usability of the RoadLens application. Responses were analyzed thematically and quantified to examine the common demands, such as design and usage preferences, feature additions. The thematic analysis generated three categories of feedback - Feature Improvement, Technical Contribution, and Functional Use. Looking at the comments, the suggestions were approximately 45% feature and interface improvement, 35% technical or performance improvement, and 20% functional or operational or training needs.

In the Feature Improvement section, requests from users were similar, where there was a desire to simplify dropdown menus, reduce required fields, and better explain definitions for distress category classifications. Many users stated there needed to be a simpler interface for classifying distress as the current dropdown options are complicated and somewhat redundantly filled out. Users were followed with great interest in being able to add other descriptive fields for example: traffic volume, road shoulder condition, drainage condition, and previous quality of repairs which were mentioned would enhance capturing the condition and context surrounding the road issues. Many respondents also requested GPS accuracy indicators and visual guides, i.e., examples of measurements to allow for more accurate and confident submissions.

Technical recommendations focused heavily on offline capabilities, better error handling, and stability of the system. Many contributors referenced problems with inconsistent internet access in the field and advocated for an offline submission option to save data locally until a connection could be made. Others suggested real time data validation, auto-capture of camera images, and photo annotation options that would support data entry. Suggestions involved automatic distress identification from the images, voice-activated or voice-command capabilities, and augmented reality markers, showing that participants are conceptualizing user-friendly technologies that will reduce manual variables while ensuring accuracy.

From an operations perspective, feedback indicated a need for more clarity on the in-app training modules and better visual examples of distress. Respondents reported difficulties in distinguishing distress types correctly, particularly without any knowledge of construction. As such, some participants said that RoadLens should work to incorporate visual representations in the forms and possibly implement processes related to the dashboard related to the distress identification. Another area of request was for tools to collaborate with teams, municipal tracking of repair requests, and notifications related to when issues were fulfilled, which demonstrate a desire for a higher sense of accountability, and to increase follow-up.

Suggestions were then ranked using a prioritization matrix that weighed user value and technical feasibility, assigning scores to high-demand items. Among the top-rated were:

- Simplified distress taxonomy
- Offline mode
- Image-assisted distress identification
- Municipality response tracking
- Distress progress tracking over time

These features are consistent with user needs for accessibility, transparency, and functionality in a crowdsourced infrastructure monitoring tool. In conclusion, the qualitative feedback reported in this study shows that RoadLens users want a more straightforward, responsive, and context-aware interface that enables them to use the tools in ways that reflect their experiences in the field. The desire for tools that better respond to field conditions; require less cognitive load, and reassure contributors that input produces actionable results is prevalent in RoadLens user comments. Invoking and applying these requests in future development cycles will provide a way for the platform to develop as a more participatory, scalable, and impactful civic technology solution for urban infrastructure management.

4.11 Recommendations for System Improvement

This section synthesizes suggestions collected from open-ended questions (columns 6, 9, and 13 of the dataset). Key insights include:

- Interface Simplification: 4 users explicitly requested simplification of dropdown menus and fewer mandatory fields.
- Offline Capability: Multiple contributors proposed offline data entry for field surveys in low-connectivity zones.
- Visual Aids: Requests were made for image-based distress classification guides and clearer definitions of categories.
- Functionality Enhancements:
    - Integration with municipal tracking for post-reporting follow-up.
    - Real-time distress validation and GPS accuracy display.
    - Dark mode and voice-command support for accessibility.

Overall, the feedback revealed a high level of constructive engagement, with 90% of users providing at least one actionable improvement idea. These insights were instrumental in shaping the iterative roadmap of the RoadLens system and highlight the importance of incorporating human-centered design principles in civic data platforms.

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Chapter 5:

Major Findings & Recommendations

This chapter summarizes the main findings from the spatial, statistical, and participatory analysis in Chapter 4. This chapter will summarize the key findings, describe their implications for the governance of urban infrastructure, and assess the extent to which this study was able to fulfil its intended scope. The task for this chapter is to summarize the patterns disclosed by the analytical results, relate those patterns to the bounds of the study, and consider the implications of the results within their large practical context, before identifying significant gaps and suggestions for improvement. The use of open-source tools and data, community participation, and GIS enabled diagnostics are all the basis of a replicable model for the monitoring of digital infrastructures. The conclusions presented in this chapter are based on empirical data and user interaction in both communities, and as such represent both the technical relevance as well as the social relevance of the study to the successful methods and principles of both participatory urban planning and road asset management.

5.1 Summary of Findings

This research project aimed to evaluate and rank the conditions of road infrastructure in Rajshahi City using a participatory GIS platform known as RoadLens. Using crowdsourced distress information and employing spatial analytic tools, this study was able to successfully illustrate how real-time contributions from civic duty can become actionable. The results discussed in Chapter 4 indicated that road distress incidents were not evenly represented across the urban network, primarily along main roads and highways where distress frequency and severity was highest in all respects at 53%. The gathering of 388 distress points indicated coverage of 34.1% of the road network in Rajshahi City, and the spatial mapping confirmed coverage bias in relation to poor road conditions for easy access along roads that are heavily-trafficked, namely; highways and main arterials.

Analysis affirmed that there were also statistical differences between road type and distress type ($\chi^2 = 77.578$, $p < 0.001$), and therefore road functionality appears to have a strong bearing on the type of surface damage the road endures. For example, main roads exhibited multiple types of distress, namely; patching and edge cracking, while highways were impacted heavily by patches and potholes, confirming that high-speed, high-load determined roadways were damaged the sport of the vehicle. In addition, the quality of drainage was also shown to be a strong factor in the severity of road distress since poorly-drained roads showed a much greater likelihood of being classified as experiencing high severity distress (again, confirmed with a significant Chi-square value; $\chi^2 = 30.269$, $p < 0.001$).

Interestingly, the analysis between traffic volume and repair urgency, although suggestive of a practical link, did not produce statistically significant results ($p = .313$), implying that other factors—such as distress type, severity, or adjacent land use—play more decisive roles in repair prioritization. Adjacent area analysis showed that zones near commercial, transportation, and mixed-use land uses consistently experienced higher severity, warranting location-sensitive planning. Kernel Density Estimation (KDE) mapping visually identified key clusters of distress in commercial corridors, market zones, and highway intersections—supporting the earlier statistical insights.

In conjunction with user engagement and feedback, it became clear that while RoadLens has been positively received, there remain opportunities for enhancements in some areas. Qualitative feedback identified a desire for offline capability, simplified UI, visual distress prompts, and further guidance for classification and codification—particularly in areas of low connectivity. The task difficulty assessments suggest that spatial reasoning needed further guidance—especially in the classification and codification of distress signals. In addition to the illustrative learning, the data we collected ultimately provided a repository that will be valuable for training subsequent models for AI utilization and automated distress identification, predictive maintenance modeling, and forecasting the health of infrastructure assets. We now have a curated, crowdsourced database of labeled images, geolocation, road attributes and context metadata that could be used for supervised machine learning and/or computer vision tasks. This data could be used in future research concerning developing AI tools for use within low-resource urban settings, and to enable the platform to go beyond manual analytics.

5.2 Alignment with System Goals and Design Intent

The results of this study confirm that the RoadLens system did operate as an effective open-source platform, facilitating the collection, visualization, and analysis of urban road infrastructure. The system combined crowdsourced distress input, geospatial harmonization, and live dashboards together which helped convert user observations into general useable infrastructure intelligence. The database component was designed on Supabase and did a good job of storing and synchronizing user submissions, including distress types, severity, road class, drainage quality, and also vehicle count. The web application was designed with more modern front-end tools, starting with Ejs rendering the application, and incorporating Leaflet.js for visualizing the data collected by the application functionally into interactive maps, heatmaps, dashboards and filters-- allowing accurate visualization of current road conditions for Rajshahi City.

This multi-component system was designed to be used as a system for data collection and as an analytical tool with the collection of data. Spatial analyses, including kernel density maps, assessments of spatial against buffer area, general statistical analyses to assess correlation of indicators were all completed on the data without needing to leave the system. These analyses helped the system identify high distress zones, understand distress level in relation to drainage, traffic or land use variances, and to assist differentiated repair prioritization use. The way the system was designed did allow both the initiators or use experts (such as planners, engineers) and the everyday use data to develop and access data in use.

Furthermore, the usability of RoadLens as an interface for surveyors and volunteers was worthwhile and efficient, given the high satisfaction and positive feedback from users. User-determined preferences for maps, live progress, and dashboards indicate that participants enjoyed being able to visualize their expedition in real time with monitoring rates, while their suggestions for enhancements, including offline mode, AR solutions, and distress classification guides for data gathering, suggest additional room for growth for the system itself. This feedback illustrates the value of a human-centered design with a GIS-augmented and open-source infrastructure monitoring tool. Overall, the system provided functional value while simultaneously illustrating a transparent, replicable, and expansible model for the other urban iteration. It highlights the role of integrated web apps as part of digital-governance or participatory planning in the provisionally sustainable management of local infrastructure. The standardized data structure conceptualized through this platform also offers the potential for uploading to machine learning datasets for large-scale smart city infrastructure datasets.

5.3 Implications for Urban Infrastructure Management

The study contributes valuable knowledge to urban road asset management by offering a hybrid approach that combines participatory data collection with spatial intelligence. Key implications include:

- Road maintenance should be prioritized not solely based on distress counts but by factoring in road type, drainage quality, adjacent land use, and severity levels.
- Drainage infrastructure must be addressed concurrently with surface maintenance to prevent recurring high-severity damages.
- Crowdsourcing can significantly bridge infrastructure data gaps in developing cities, especially when paired with mobile-friendly and localized interfaces.
- Functional zones like commercial or transport hubs should be inspected more frequently due to their exposure to accelerated surface wear.

5.3.1 Fostering a Culture of Civic Engagement:

RoadLens has social benefits in addition to technical value; it creates a sense of ownership and co-responsibility. With RoadLens users are no longer passive road users, they engage with their previous neighborhood passively, and now they are empowered to report, track and visualize road conditions. This civic engagement creates trust between residents and government, and promotes participatory governance. These peer tools become especially important in jurisdictions where institutions consistently fail to take care of road money, as they not only promote mutual accountability, but they facilitate a level of citizen engagement and inclusiveness in the public service delivery.

5.3.2 Promoting Transparency and Accountability:

The open-access format of the RoadLens platform adds another layer of transparency to the management of urban infrastructure. Public access to road condition data, severity ratings, and user reports makes it extremely difficult for authorities to hide or procrastinate necessary repairs. The eventuality of public scrutiny and transparency should create constructed pressure on municipal agencies to act more rapidly and transparently. Furthermore, this format would produce an evidentiary trail of civic reporting and government response—potentially eliminating the opaqueness that generates corruption, misappropriation of funds, or inattention.

5.3.4 Informing Urban Planning and Budgeting:

Although reactive maintenance is the primary use of the system, the real long-term value of RoadLens is in its ability to help with decisions related to strategic infrastructure investments. With time, future spatial and statistical trends in the dataset can help planners identify chronic failing roadway segments, repeated drainage issues and stresses relating to land-use. Rather than just patching the pavement again and again, cities may want to consider complete redesigns, drainage system upgrades or, in some instances, rezoning. The platform offers a reliable, factual basis point for long-term infrastructure budgeting practices, life-cycle cost analysis, and capital improvement planning.

5.3.5 AI-Ready Infrastructure Datasets:

Data that has been collected can serve as a continuing repository that benefits continuous improvement of algorithms and states of readiness for AI to facilitate predictive modeling and smart use of maintenance budgets. As smart city initiatives are pursued globally, labeled, spatial infrastructure data will become invaluable to train smart systems that will expand on automation through early warning systems, addressing maintenance priority areas and correcting interventions.

5.3.6 Scalable to Other Civic Infrastructure Domains:

The participatory framework set out here could also be used in other areas--e.g. waste management, utilities outage tracking, public space safety, waterlogging information--where citizen data respond to government and responsible governance. The crowdsourcing platform could reflect various infrastructural domains aligned to similarly to the data schemas and classification protocols to empower the public and adopt citizen ownership within each area of infrastructure.

5.4 Recommendations for Future Research

- Expansion of Contributor Base: A more diverse and well-trained pool of contributors could improve data quality and coverage across all road types.
- Automated Distress Detection: Future iterations of RoadLens should integrate AI-based image classification to reduce subjective bias in distress identification.

- Multi-variable Analysis: Incorporating more explanatory variables such as pavement age, previous repairs, traffic composition, and weather patterns can refine prioritization models.

- Longitudinal Tracking: Adding features for progress tracking of reported issues can provide insights into repair efficiency and impact of intervention.

- Localized Interface: Including Bangla and regional dialects in the user interface may increase inclusivity and engagement.

- AI Training Readiness: Ensure the database is regularly cleaned, labeled, and structured for easy export to machine learning workflows. Future AI-driven research could focus on transfer learning in distress identification, comparative city analysis, or infrastructure deterioration modeling under varying socio-environmental factors.

This study reinforces the power of integrating public participation with spatial analysis in addressing urban infrastructure challenges. By utilizing a bottom-up data collection model supported by analytical rigor, the research offers a replicable and scalable model for other cities seeking sustainable and responsive road maintenance strategies.

Chapter 6:

Conclusions

The deployment of the RoadLens platform in Rajshahi City has shown the practicability and potential of a participatory model, using GIS, for monitoring road infrastructure. This research has gone beyond assessing a technical prototype and has developed a framework for civic engagement, data collection, spatial analysis, and governance feedback. The findings of this pilot implementation demonstrate that a participatory, geo-spatial peer review on road monitoring has the potential to address the data and monitoring gaps that still remain in many low- and middle-income countries, and especially in rapidly urbanizing contexts where traditional models of infrastructure management have failed to respond with equal vigor to the growing demand for infrastructure.

Although the platform was implemented in the particular context of Rajshahi, the principles of design and system architecture behind it were built to be adaptable. RoadLens presents a modular, scalable, and cost-effective model that could be duplicated in other cities with similar kinds of infrastructural problems. The use of open-source technologies and cloud solutions enables municipal authorities to implement the system in a manner that is either for free or does not bind them into a proprietary software trap. This is especially relevant for resource-strained municipalities that typically do not have the capacity to make use of an all-stone asset management system. The shared reliance on citizen participation also means that data collection is constantly ongoing, flexible, and in response to actually occurring local conditions rather than through a simply periodic top-down survey.

The potential of RoadLens extends far beyond the monitoring of road conditions alone. The participatory architecture can be easily adapted to support other types of civic monitoring, such as reporting broken streetlights, documenting illegal dumping, identifying waterlogging areas, or mapping urban sanitation problems. By adjusting the variable schema and modifying the survey interface, RoadLens could become a generalized urban issue reporting platform—capable of fostering multi-sectoral civic engagement. This flexibility is a key strength of the system and reinforces its relevance in cities where multiple layers of infrastructure deficiencies coexist and where responsive governance requires a holistic understanding of local challenges.

RoadLens' possibilities go way beyond just road condition monitoring. The participatory architecture could easily be extended to provide support for other types of civic monitoring, such as: reporting broken streetlights, documenting illegal dumping, identifying areas of waterlogging or mapping urban sanitation issues. By adapting the variable schema and editing the survey interface, RoadLens could easily function as a generalized urban issue reporting platform—able to facilitate multi-sectoral civic awareness. This versatility is a significant strength of the system and is more pertinent to cities that have multiple levels of dysfunction in the infrastructure and where responsive governance needs a whole understanding of local problems.

The inclusion of advanced spatial analysis tools adds another level of sophistication to the platform. Hot Spot Analysis through the Getis-Ord Gi* statistic allows users to move beyond location, and distinctions, and to move towards inferential spatial reasoning. From showing just where the most frequent reports occur, to identifying statistically valid locations of clusters of large size, high severity damage. These levels of understanding have tremendous value for municipal decision-makers when figuring out priorities for repairs and how to effectively allocate their limited budgets. For these reasons, RoadLens' use of statistically validated outputs lends additional rigor to RoadLens' outputs, and at least asserts that participatory data are not simply anecdotal or untrustworthy.

This study also illustrates the valuable point of the need to match technological innovation with institutional realities. For example, a well-built app can't create meaningful impact if the outputs don't ever get adopted into the official government workflow. RoadLens acknowledges this and actively proposes pathways to encourage municipal uptake of its data, such as standardizing datasets, working in conjunction with CMMS systems, and identifying formal pathways of communication with the relevant authorities. Otherwise, the platform has significant risk of being seen as an academic project, or simply another pilot, with minimal tangible impact to real-world outcomes. The ultimate success of RoadLens will rely directly on the willingness and capacity of urban governments, like Rajshahi City Corporation, to view citizen-generated data as relevant and meaningful.

Just as important as the other facets of the project is the attention it has paid to the ethical and social aspects of participatory data collection. In a time when platforms and other tools take advantage of ubiquitous human behaviors through processes like gamification and persuasive technology, RoadLens takes advantage of a human-centered approach. RoadLens does not rely on higher competition, moreover it prioritizes participation around collaboration through features like collaborative mapping and contributor acknowledgment. RoadLens allows contributors to receive a contribution evaluation to ensure quality while trying to limit the barriers to participation. RoadLens's planned features like offline data collection, local language of the interface, and map-based navigation indicate that the platform tries to be usable and inclusive for different digital literacy levels. The key understanding is that any good civic technology should not simply be effective but equitable, empowering, and transparent.

In addition, the participatory model incorporated in this work advances the global discussion of civic co-production and resilience. While citizens are at times perceived merely as beneficiaries or complainants, RoadLens considers citizens as co-authors of urban intelligence. This paradigmatic shift in how city systems can function involves information flowing in both directions, distributed governance and accountability. Because trust in public institutions is currently very low in many parts of the world, particularly in developing areas, this is a model that can begin rebuilding civic engagement by showing the public that participation is significant, and leads to real action.

Finally, the larger implications of this research are located in its contribution to the future of digital governance. RoadLens represents a model combining mobile technologies, open-source platforms, and participatory models into a usable, impactful governance mechanism. Its relevance is not restrained to urban planning or civil engineering; its domains encompass public policy, development studies, human-computer interaction, and geospatial science. It is a model of interdisciplinary thinking and practical design yielding innovations based on community realities but stretching dreams far beyond what is accepted as possible.

Ultimately, this research showed that digital tools can help communities become active stewards of their environment--despite challenges faced by the city's infrastructure and institution. RoadLens is not simply a platform (or a system or a dashboard); it is a platform for participatory democracy in the smart city age. As a user, it promotes users to create knowledge, co-create value, and demand accountability from systems. Its achievements to date signal that there is a pathway forward—not only for Rajshahi but for the vast majority of cities in the

Global South, who want to modernize governance while also enhancing citizen engagement. With continued refinement, institutionalization, and user-led development, RoadLens can be a first layer of information intelligence (foundational) that demonstrates that inclusive innovation is possible--and perhaps, essential to the sustainable urban future.

References

References:

Adewumi, A. A. (2022). *Reviewing the challenges of achieving sustainable road infrastructure in developing nations*. Retrieved from https://www.researchgate.net/publication/366529375

Al-Rousan, T., & Khedaywi, T. (2022). *Applications of crowdsourcing in sustainable urban development planning in the Global South*. MDPI.

Antoniou, V., et al. (2025). *Gamifying engagement in spatial crowdsourcing: An exploratory mixed-methods study on gamification impact among university students*. Preprints.org.

ArcGIS Pro. (n.d.). *How Hot Spot Analysis (Getis-Ord Gi) works*. Retrieved from https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-statistics/h-how-hot-spot-analysis-getis-ord-gi-spatial-stati.htm

Beck, S., & Mitkiewicz, K. (2025). A systematic literature review of citizen science in urban studies and regional urban planning: Policy, practical, and research implications. *Urban Ecosystems*, 28(2).

Biessmann, F., Golebiowski, J., Rukat, T., Lange, D., & Schmidt, P. (2021). *Automated data validation in machine learning systems*. Amazon Science.

Bowser, A., et al. (2021). Data quality in citizen science. In B. Balázs, D. D. G. de Vries, & J. P. Spiers (Eds.), *Citizen science: A study of people, expertise and innovation*. Ubiquity Press.

Brand, R. (2005). Urban infrastructures and sustainable social practices. *Journal of Urban Technology*, *12*(2), 1–25. https://doi.org/10.1080/10630730500307128

Cities of Service. (n.d.). *Citizen-Sourced Data in Your City*. Retrieved from https://citiesofservice.jhu.edu/resource/citizen-sourced-data-city/

Crowdsourcing Week. (2025). *Crowdsourced Urban Planning: Designing Cities with Community Input*. Retrieved from https://crowdsourcingweek.com/blog/designing-cities-with-community-input/

Chen, T., et al. (2014). *Architecture for smart-safe city monitoring*. https://doi.org/10.1109/ICMTMA.2014.40

Dalla Longa, R. (2023). *Urban Infrastructure*. Springer. https://doi.org/10.1007/978-3-031-23785-0_1

Douangphachanh, V., & Oneyama, H. (2024). *Using smartphones to estimate road pavement condition*. https://doi.org/10.14453/isngi2013.proc.16

Du, P., et al. (2023). *Integrated planning and budgeting for public investment*. International Monetary Fund.

Federation of Canadian Municipalities (FCM). (2022). *Asset management insights: Data and information*. Retrieved from https://fcm.ca/en/resources/mamp/asset-management-insights-data-and-information

Gharesifard, M., et al. (2021). Meeting volunteer expectations — A review of volunteer motivations in citizen science and best practices for their retention through implementation of functional features in CS tools. *Journal of Environmental Planning and Management*, 64(10), 186–205

Government of the People's Republic of Bangladesh. (2001). *Road Condition Survey Manual*.

Hasan, M., Ganguly, B., Chowdhury, S. R., Rahman, G. A., Sami, S., Sultana, J., Kafy, A. A., & Das, A. (2021). "Analyzing the Impact of Land Use and Roadside Informal Activity on Transportation System: A Case Study in Rajshahi City Corporation, Bangladesh." International Journal of Urban and Regional Planning, 4(3), 12-25.

Harris, D. K., Alipour, M., Acton, S. T., Messeri, L. R., Vaccari, A., & Barnes, L. E. (2017). *The citizen engineer: Urban infrastructure monitoring via crowd-sourced data analytics*.

Hazaymeh, K., & Alomari, A. H. (2022). Spatiotemporal analysis of traffic accidents hotspots based on geospatial techniques. *ISPRS International Journal of Geo-Information*, 11(4), 260. https://doi.org/10.3390/ijgi11040260

Hussain, S., Memon, Z. A., Gunga, L., Razuhanafi, M., Yazid, M., Rahim, A., Mubaraki, M., & Izzi, N. (2021). Low-cost pavement management system for developing countries. *Sustainability*, *13*(11), 5941. https://doi.org/10.3390/su13115941

Iacovides, I., et al. (2018). Do games attract or sustain engagement in citizen science: A study of volunteer motivations. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*.

Kim, T. W., & Werbach, K. (2017). Ethical issues in gamification. *Journal of Business Ethics*, 146(4), 915–929.

Klauser, F. R., & Albrechtslund, A. (2014). *From self-tracking to smart urban infrastructures:* Towards an interdisciplinary research agenda on Big Data. Surveillance & Society, 12(2), 219-235. https://doi.org/10.24908/ss.v12i2.4605

Manepalli, U. R. (2011). A comparison of kernel density estimation and Getis-Ord Gi statistic for hotspot identification in transportation safety. *Transportation Research Board*.

NumberAnalytics. (2025). *Advanced Crowdsourced GIS Techniques*. Retrieved from https://www.numberanalytics.com/blog/advanced-crowdsourced-gis-techniques

NumberAnalytics. (n.d.-b). *Data Standards in Smart Cities*. Retrieved from https://www.numberanalytics.com/blog/data-standards-in-smart-cities

Obedin, A. V., Soroka, E. O., Kukartsev, V. V., Mikhalev, A. S., Tynchenko, V. S., Semenova, E. I., & Bashmur, K. A. (2019). The developing program system of social monitoring of road improvement and urban infrastructure. *Journal of Physics: Conference Series*, *1399*(5), 055021. https://doi.org/10.1088/1742-6596/1399/5/055021

OECD. (2025). *What is citizen science and why should policymakers care?* Retrieved from https://www.oecd.org/en/blogs/2025/04/what-is-citizen-science-and-why-should-policymakers-care.html

Ojo, S. A., Olusina, J. O., Ngene, B. U., Busari, A. A., Adediran, J., & Eletu, A. (2019). Assessment of road infrastructure using remote sensing and GIS methodology for monitoring the condition of paved and unpaved roads. https://doi.org/10.1088/1757-899X/640/1/012099

Onuigbo, I. C., & Orisakwe, K. U. (2013). Applications of GIS and remote sensing in road monitoring in Minna and environs, Nigeria. *IOSR-JESTFT*, *3*(6), 1–5. https://www.iosrjournals.org/iosr-jestft/papers/vol3-issue6/A0360105.pdf

Pouliquen, P., Harral, C., Faiz, A., Bennathan, E., Smith, G., Bhandari, A., Johansen, F., Fossberg, P., Paterson, W., & Holland, E. (1988). *The state of the roads*. The World Bank

Quintero, A., & Pierre, S. (2002). *A knowledge-based approach for managing urban infrastructures*. DOI: 10.1016/S0950-7051(02)00028-X.

Rahman, F. I., & Hasnat, A. (2020). "Case Study on Transportation System in Rajshahi City, Bangladesh." International Journal of Transportation Engineering and Traffic System, 4(2), 1-15.

Ramesh, A. (2021). *Cloud-based collaborative road surface monitoring using deep learning and smartphones* (Master's thesis). Clemson University. https://tigerprints.clemson.edu/all_theses/3637

Scolamiero, V., Boccardo, P., & La Riccia, L. (2025). Mobile Mapping System for Urban Infrastructure Monitoring: Digital Twin Implementation in Road Asset Management. *Land*, *14*(3), 597. https://doi.org/10.3390/land14030597

Shahzad, M. (2020). A review of hot spot analysis techniques for transportation safety. *Journal of Transport Geography*, 85, 102712.

Smartico. (2025). *Ethical Considerations in Gamification*. Retrieved from https://www.smartico.ai/blog-post/ethical-considerations-in-gamification

Straub, S. (2016). Infrastructure and growth in developing countries: Recent advances and research challenges (World Bank Policy Research Working Paper No. 4460). World Bank.

The Urban Infrastructure. (n.d.). Encyclopedia of European Social History. Encyclopedia.com. Retrieved May 5, 2025, from https://www.encyclopedia.com

UN-Stats. (n.d.). *Citizen Data*. Retrieved from https://unstats.un.org/UNSDWebsite/citizen-data/

Wiggins, A., et al. (2012). Mechanisms for data quality and validation in citizen science. *Proceedings of the 2012 I Conference*

Appendix

Figure: Wide Crack

Figure: Narrow Crack

Figure: Edge Crack

Figure: Narrow Crack

Figure: Patching

Figure: Pavement distress

Figure: Potholes

Figure: Edge cracks

Figure: Transverse Cracks

Figure: Raveling cracks

Figure: High-severity pothole.

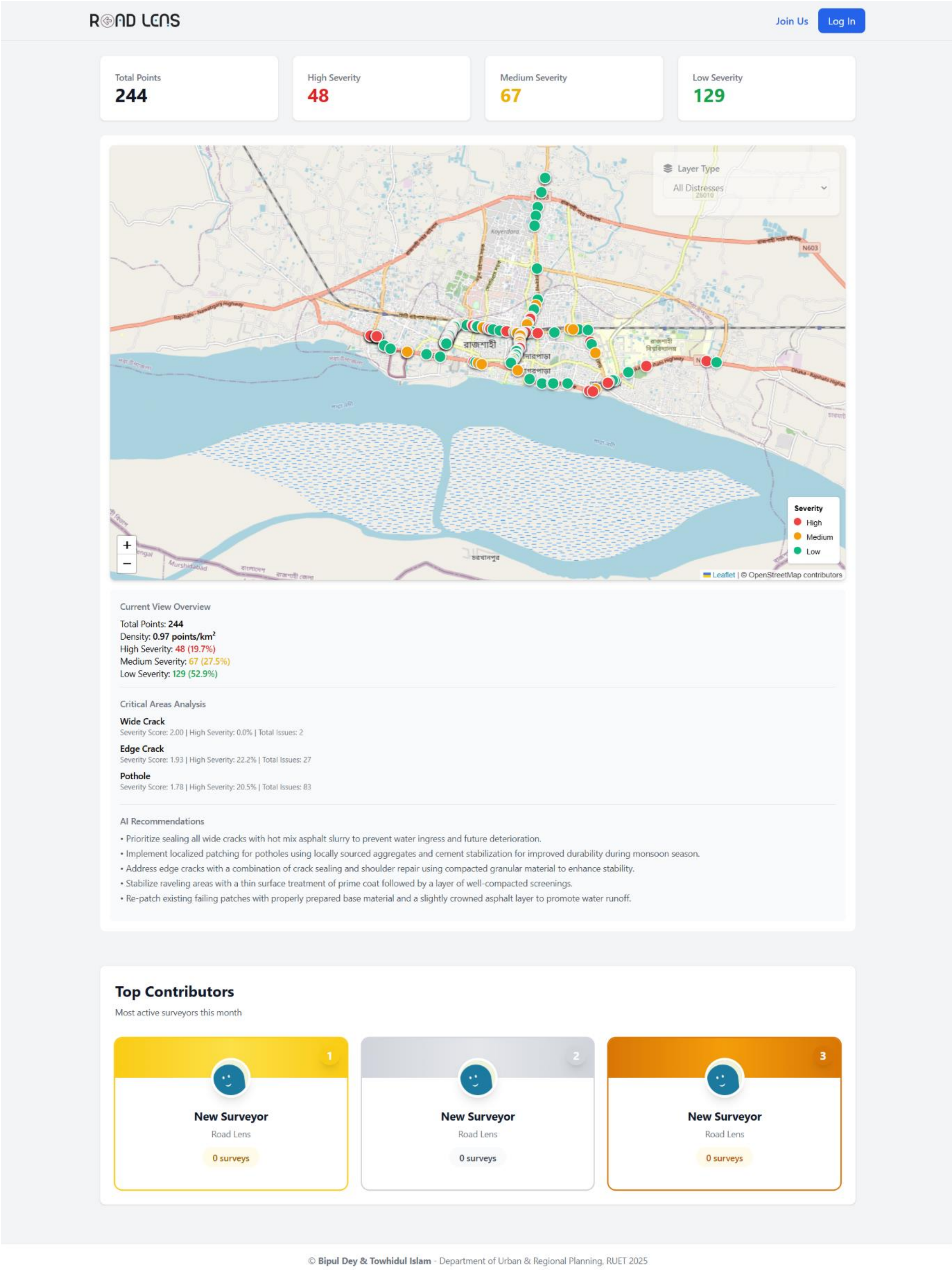
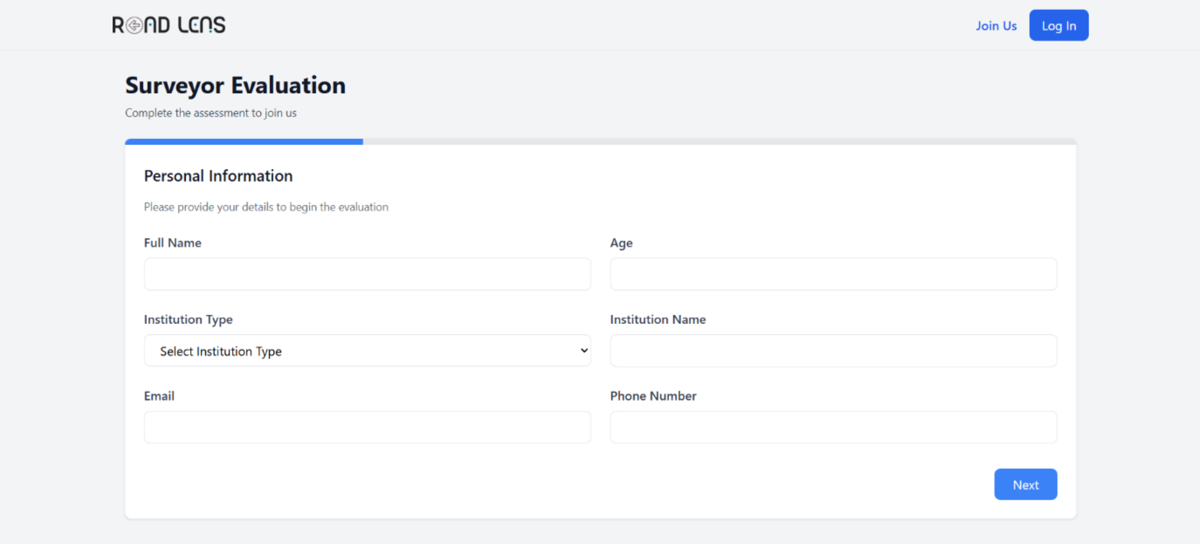
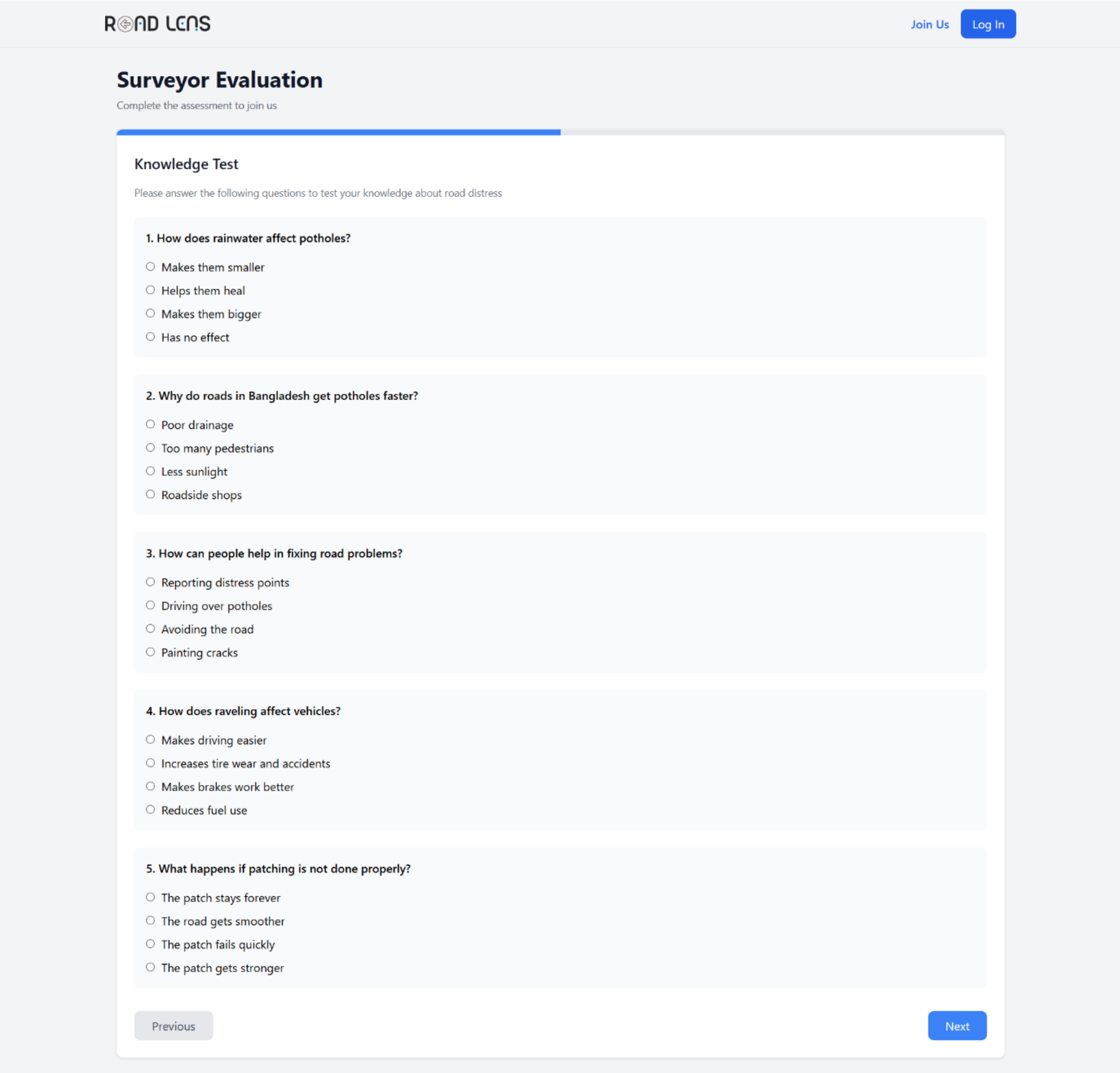


Figure: RoadLens (Landing page) - https://roadlens.my.to/



Figures: RoadLens (Evaluation) - https://roadlens.my.to/evaluation



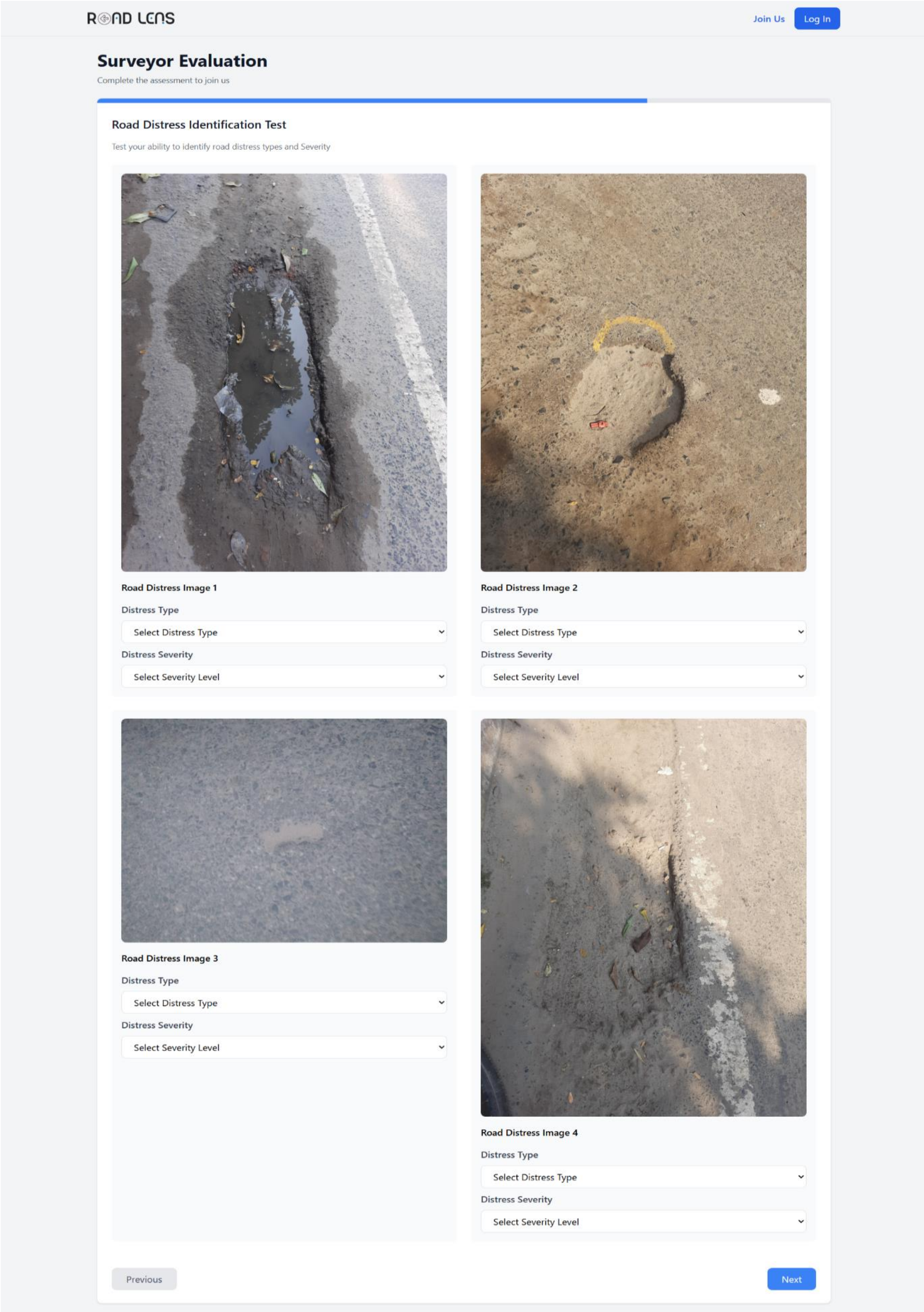
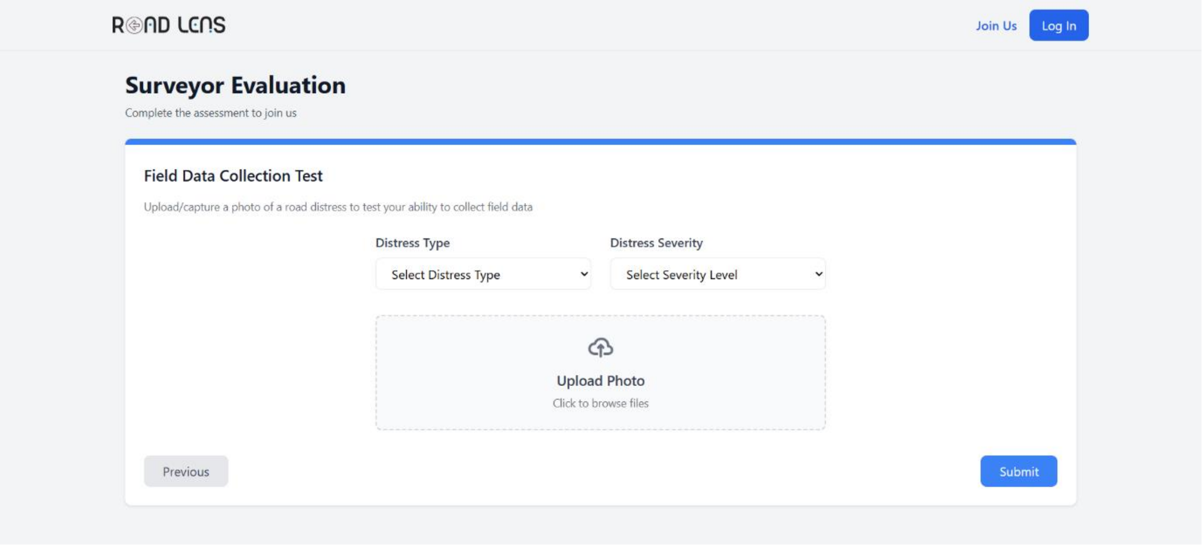


Figure: RoadLens (Evaluation) - https://roadlens.my.to/evaluation



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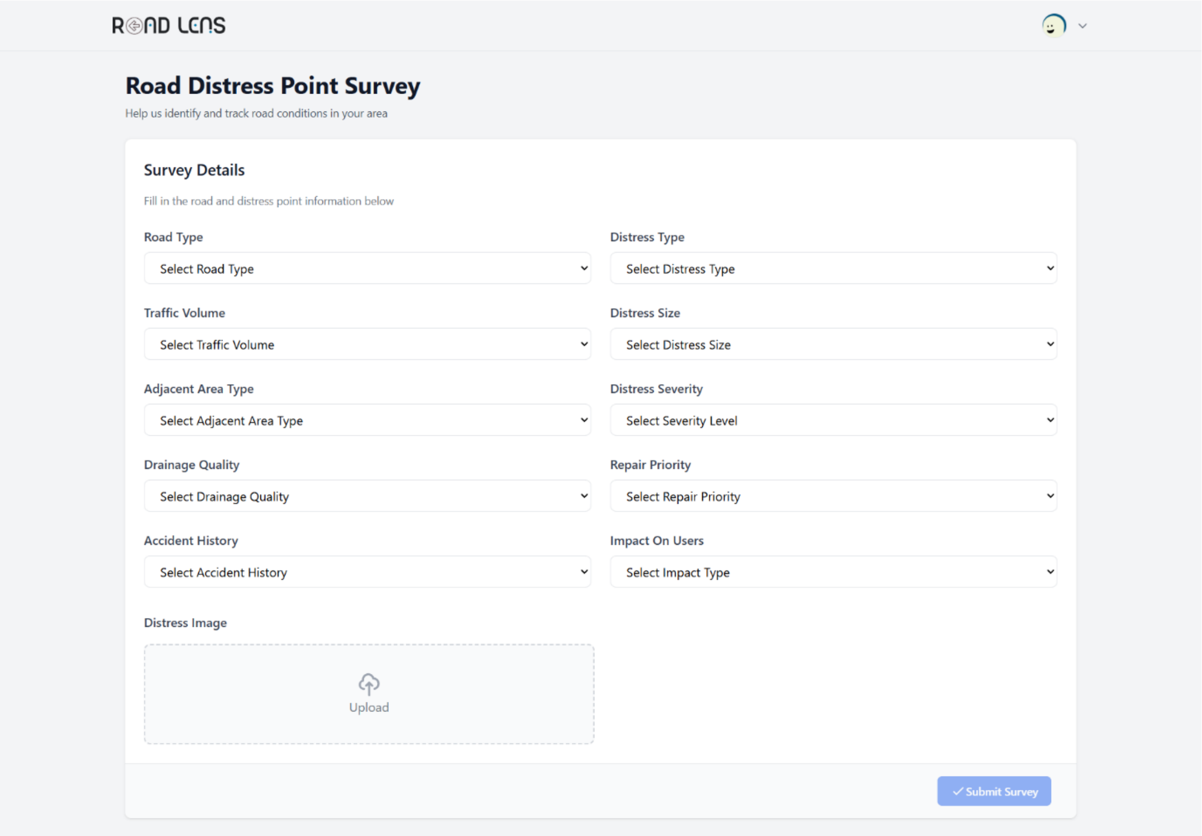


Figure: RoadLens (Submit New Survey) - https://roadlens.my.to/survey

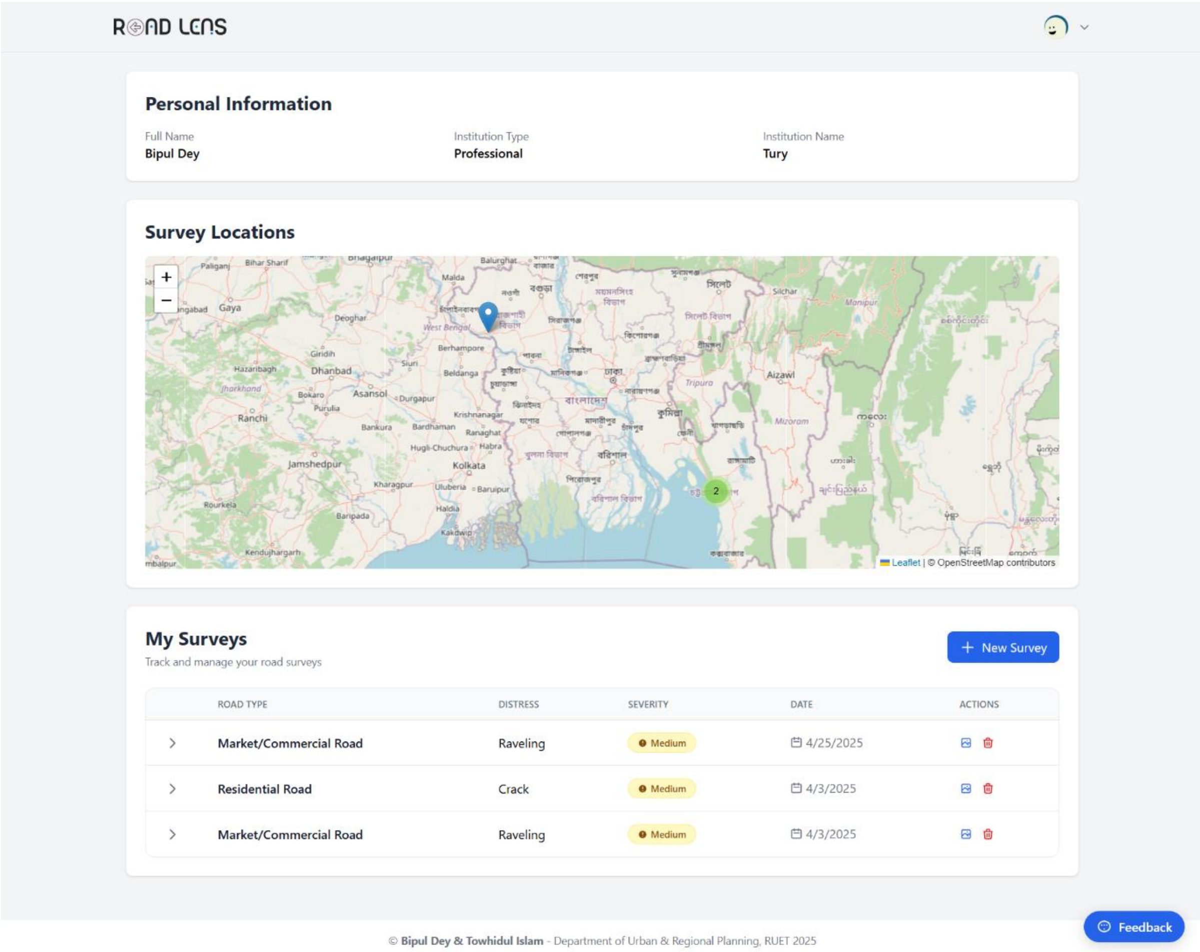
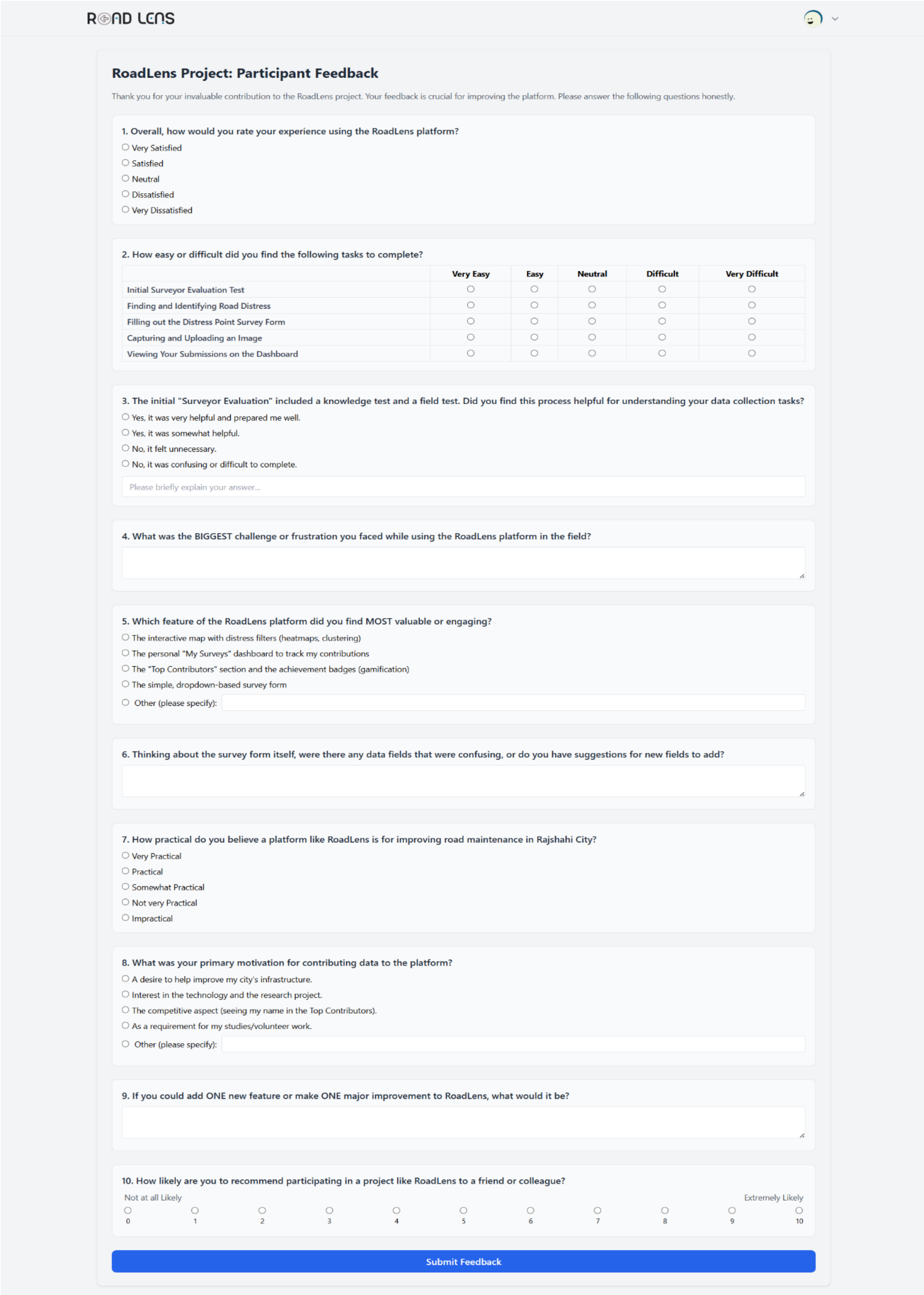


Figure: RoadLens (My Surveys) - https://roadlens.my.to/my-surveys



ROAD LENS

RoadLens Project: Participant Feedback

Thank you for your invaluable contribution to the RoadLens project. Your feedback is crucial for improving the platform. Please answer the following questions honestly.

1. Overall, how would you rate your experience using the RoadLens platform?
- ○ Very Satisfied
- ○ Satisfied
- ○ Neutral
- ○ Dissatisfied
- ○ Very Dissatisfied

2. How easy or difficult did you find the following tasks to complete?

	Very Easy	Easy	Neutral	Difficult	Very Difficult
Initial Surveyor Evaluation Test	○	○	○	○	○
Finding and Identifying Road Distress	○	○	○	○	○
Filling out the Distress Point Survey Form	○	○	○	○	○
Capturing and Uploading an Image	○	○	○	○	○
Viewing Your Submissions on the Dashboard	○	○	○	○	○

3. The initial "Surveyor Evaluation" included a knowledge test and a field test. Did you find this process helpful for understanding your data collection tasks?
- ○ Yes, it was very helpful and prepared me well.
- ○ Yes, it was somewhat helpful.
- ○ No, it felt unnecessary.
- ○ No, it was confusing or difficult to complete.

Please briefly explain your answer...

4. What was the BIGGEST challenge or frustration you faced while using the RoadLens platform in the field?

5. Which feature of the RoadLens platform did you find MOST valuable or engaging?
- ○ The interactive map with distress filters (heatmaps, clustering)
- ○ The personal "My Surveys" dashboard to track my contributions
- ○ The "Top Contributors" section and the achievement badges (gamification)
- ○ The simple, dropdown-based survey form
- ○ Other (please specify):

6. Thinking about the survey form itself, were there any data fields that were confusing, or do you have suggestions for new fields to add?

7. How practical do you believe a platform like RoadLens is for improving road maintenance in Rajshahi City?
- ○ Very Practical
- ○ Practical
- ○ Somewhat Practical
- ○ Not very Practical
- ○ Impractical

8. What was your primary motivation for contributing data to the platform?
- ○ A desire to help improve my city's infrastructure.
- ○ Interest in the technology and the research project.
- ○ The competitive aspect (seeing my name in the Top Contributors).
- ○ As a requirement for my studies/volunteer work.
- ○ Other (please specify):

9. If you could add ONE new feature or make ONE major improvement to RoadLens, what would it be?

10. How likely are you to recommend participating in a project like RoadLens to a friend or colleague?

Not at all Likely — Extremely Likely

○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

Submit Feedback

Figure: RoadLens (Contributors Feedback) - https://roadlens.my.to/feedback

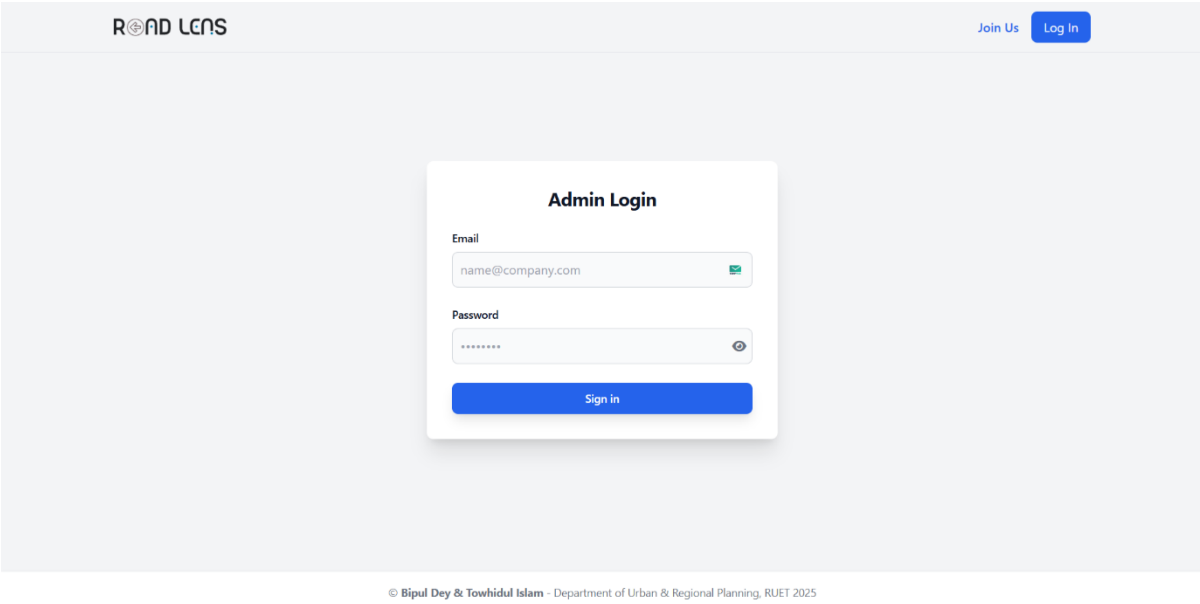


Figure: RoadLens (Admin Login) - https://roadlens.my.to/admin/login

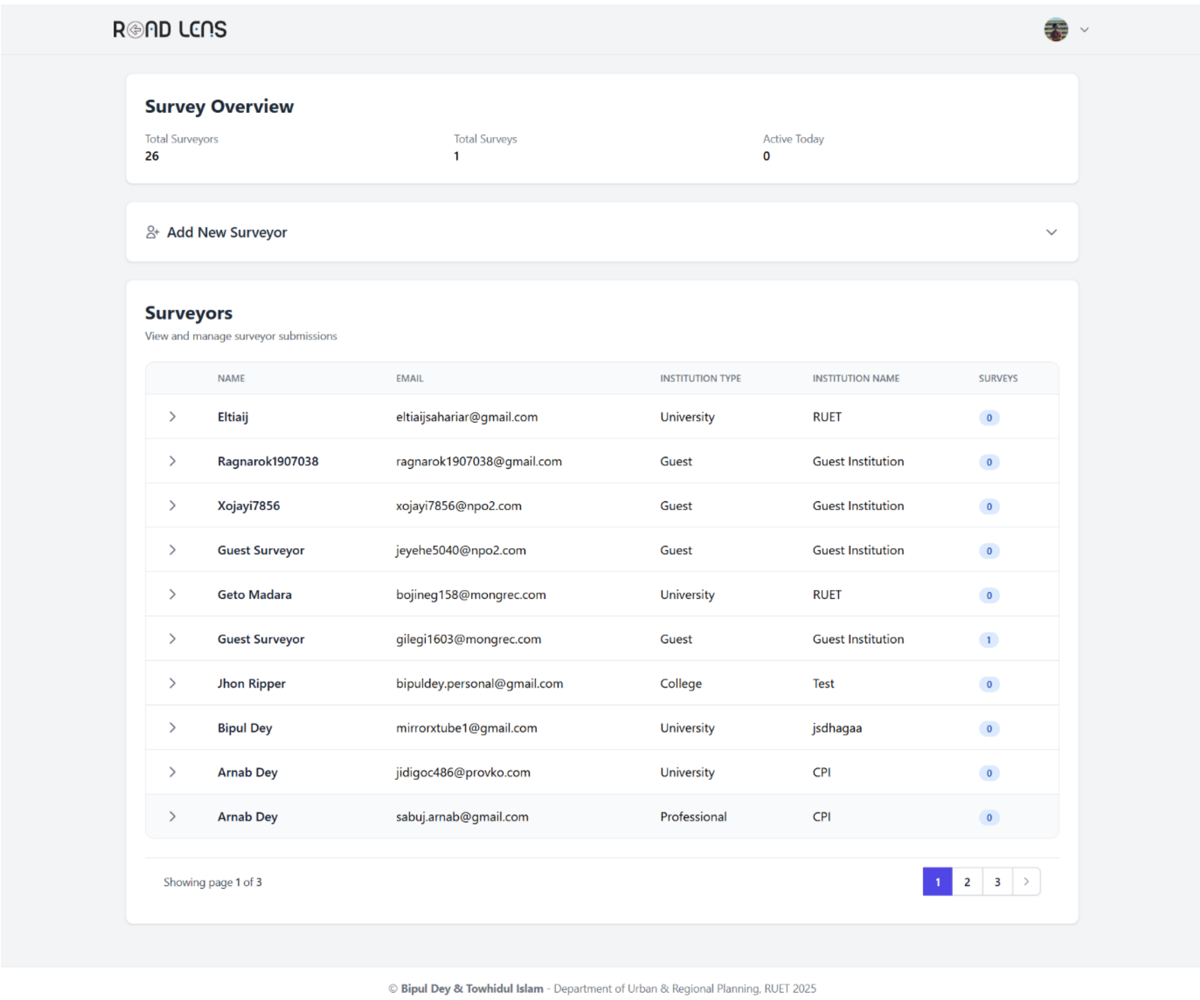


Figure: RoadLens (Survey Dashboard) - https://roadlens.my.to/admin/survey-dashboard

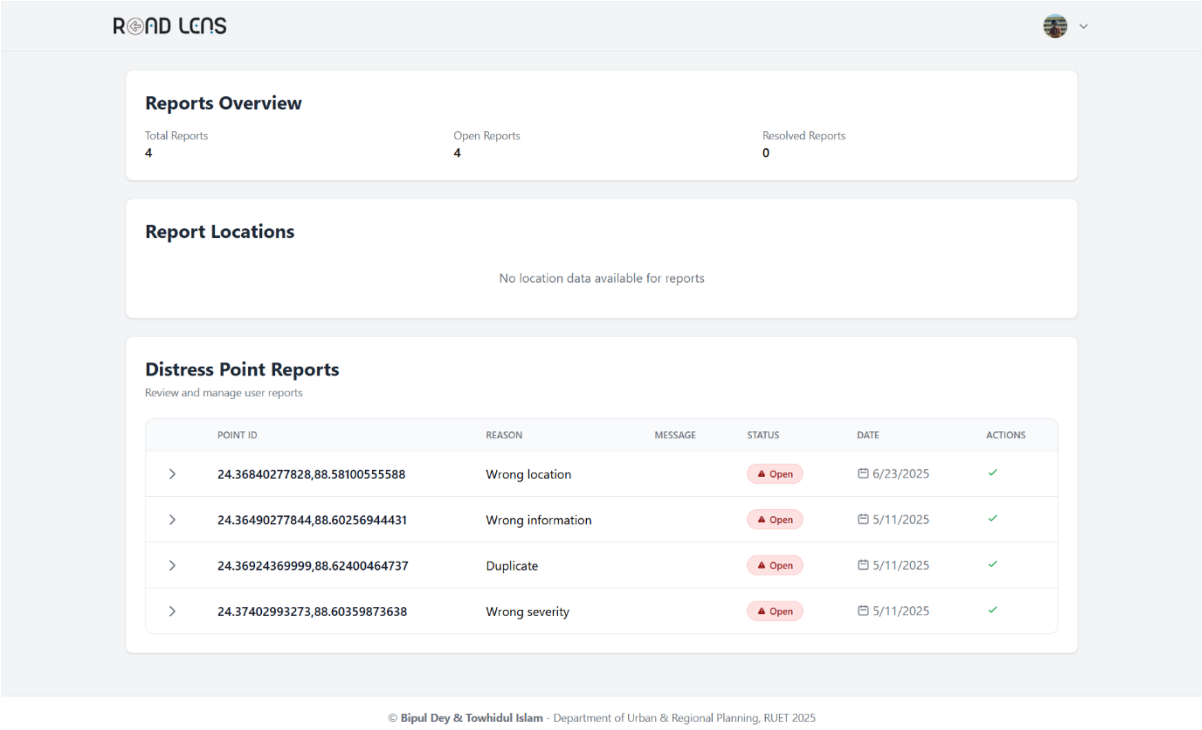


Figure: RoadLens (Reports) - https://roadlens.my.to/admin/reports

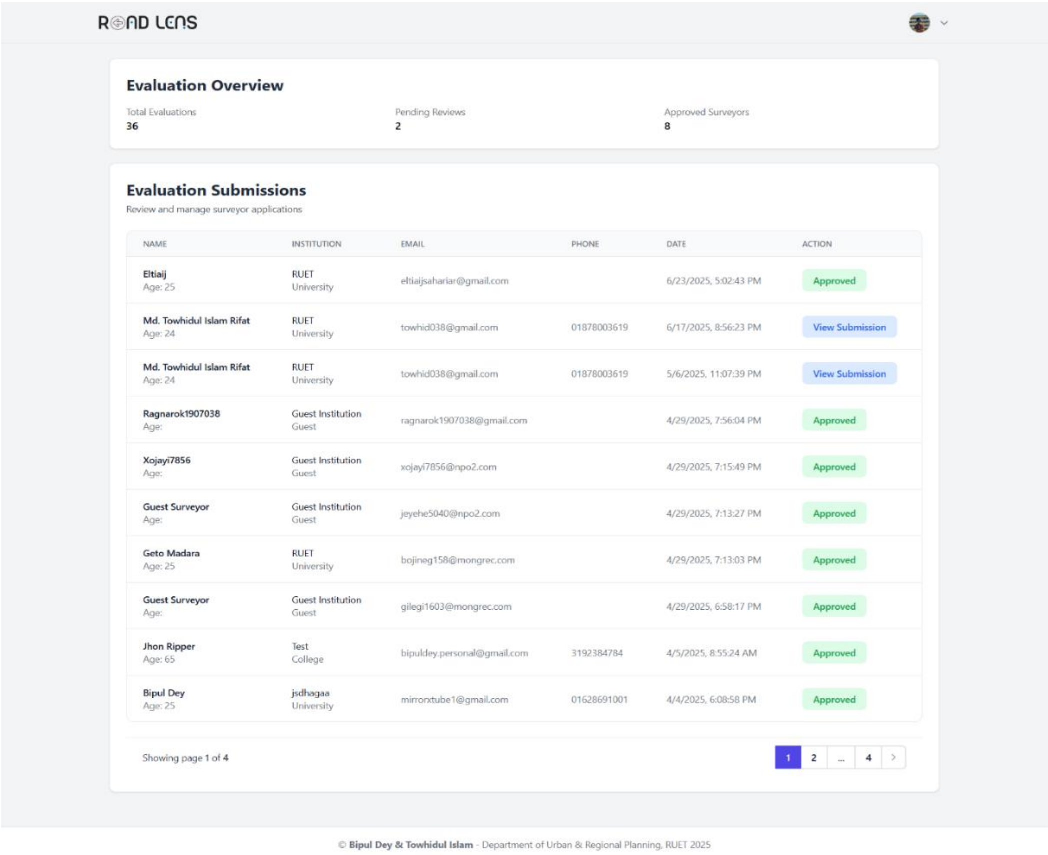


Figure: RoadLens (Evaluation Dashboard) - https://roadlens.my.to/admin/evaluation-dashboard

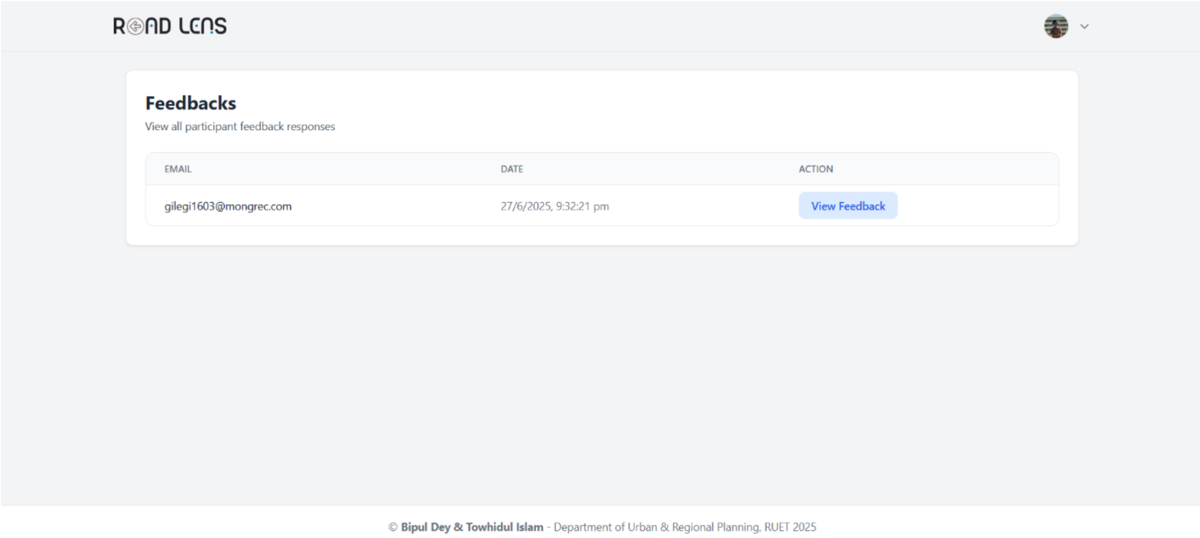


Figure: RoadLens (Feedback Dashboard): https://roadlens.my.to/admin/feedbacks

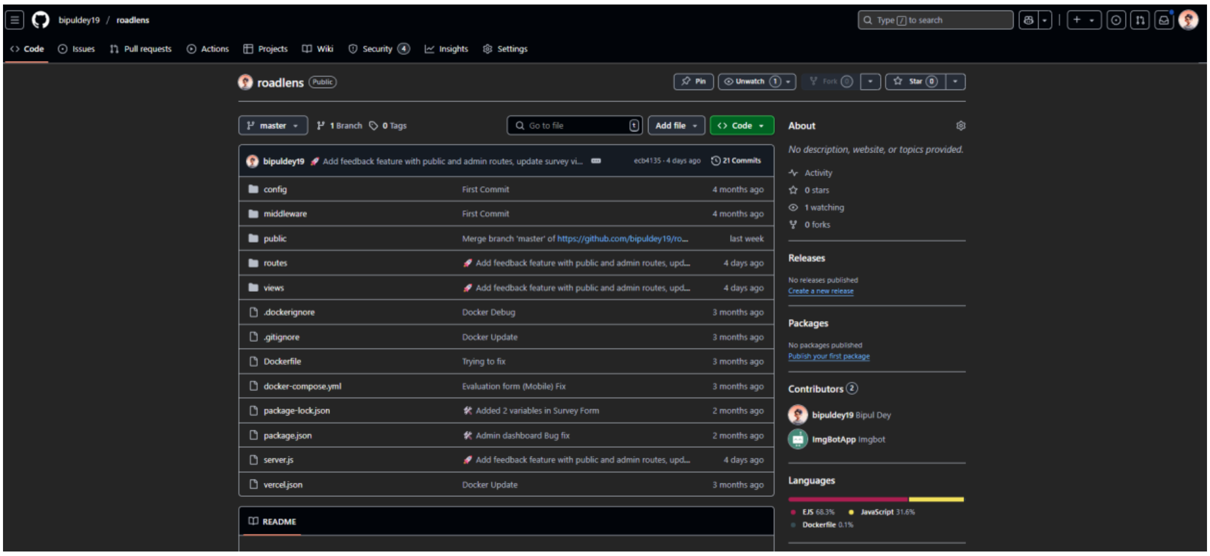


Figure: RoadLens Github Repository - https://github.com/bipuldey19/roadlens