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HazWatch: A Geospatial Citizen Science Platform Integrating Multi-Hazard Reporting with Data Access and Spatial Analysis in India

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Abstract

The increasing frequency, and intensity of natural hazards coupled with vast area, India necessitates a wider spatial coverage of high-resolution, real-time datasets for effective disaster risk assessment and research. However, existing data collection systems remain largely centralized and fragmented, often lacking the spatial and temporal granularity required to capture localized events. This study presents HazWatch, an operationally developed and fully implemented, a geospatial citizen science–based mobile platform designed to facilitate crowdsourced multi-hazard reporting, structured data generation, and controlled data dissemination across India. It enables people become data contributors from data points. The system integrates a user-facing mobile interface with a backend processing pipeline and an administrative governance framework. Users can report hazard events through a standardized multi-stage workflow, capturing spatial coordinates, temporal attributes, hazard categories, affected areas, and photographic evidence. These reports are geocoded, stored, and visualized through an interactive map interface, enabling spatial exploration and generation of basic geospatial insights, including hazard frequency, spatial distribution, administrative-level coverage. For validation the system keeps human-in-the-loop moderation mechanism, where submitted reports undergo time to time review. This enables removal of erroneous or redundant entries and supports progressive improvement of dataset reliability. In addition, the system provides controlled access to anonymized geospatial datasets through an approval-based framework, ensuring privacy preservation while maintaining data utility for research applications. By integrating data acquisition, spatial visualization, analytics, and governance within a unified framework, HazWatch offers a scalable, cost-effective approach for bridging citizen-generated observations with structured geospatial data systems, enhancing hazard data availability and usability in India.

1. Introduction

Natural disasters have emerged as a growing global concern, with increasing frequency, intensity, and spatial variability (IPCC, 2021; Dash and Paul, 2020). India, owing to its vast geographical extent of approximately 3.2 million square kilometers and diverse physiographic and climatic conditions, is highly vulnerable to a wide range of hazards, including landslides, floods, debris flows, avalanches, and glacial lake outburst floods (GLOFs) (NDMA, 2020; IMD, 2020; Gupta et al., 2016). The dispersion of population across remote, mountainous, rural, and densely populated urban regions further complicates systematic monitoring and data collection (Khan, 2020). Effective disaster risk assessment depends on the availability of accurate, timely, and spatially distributed data (Khan, 2023; UNEP, 2021; UNDRR, 2019). However, in India, existing data collection mechanisms remain largely centralized and fragmented, often lacking the resolution and immediacy required to capture localized events (Khan, 2021; NDMA, 2020). Consequently, a significant gap persists between ground-level occurrences and structured datasets available for analysis, limiting both situational awareness and research potential (NASA, 2022; Khan et al., 2022).

However, the rapid expansion of smartphones and internet connectivity has created an opportunity to leverage citizens as distributed data contributors rather than merely a vulnerable population (Haklay, 2013). Crowdsourcing offers a scalable and cost-effective approach to capturing real-time, location-specific information across geographically dispersed and hard-to-reach areas, which would otherwise require significant time, manpower, and financial resources through conventional field-based data collection systems (Goodchild, 2007). Despite this potential, existing disaster-related mobile applications in India remain limited in functionality, integration, and data accessibility (Reuter, Hughes, & Kaufhold, 2018; Meier, 2015). In particular, there is a lack of systems that not only collect user-generated data but also structure, analyze, and disseminate it for both public use and research purposes (Singh et al., 2018; Resch et al., 2018 and See et al., 2016).

To address this gap, the present work full implementation, and closed beta-stage deployment HazWatch, a crowdsourced mobile application that enables real-time and retrospective collection of geocoded hazard data, provides users with in-app insights, and disseminates structured, anonymized datasets for spatial analysis and research purposes. At the time of submission of this manuscript, the HazWatch mobile application was already undergoing closed beta testing following its submission to the Google Play Store in order to evaluate system functionality, usability, and operational performance under controlled real-world conditions. It supports the reporting of multiple types, including landslides, floods, flash floods, urban floods, heat waves, mudflows, debris flows, avalanches, GLOFs, and “other”, along with associated spatial and temporal attributes.

The system is designed as an integrated data pipeline that facilitates the collection, storage, and organization of user-submitted data. The collected information is geocoded and structured to enable spatial analysis. Building upon this dataset, the system incorporates analytical components that generate insights into hazard distribution and trends, including spatial patterns across regions and temporal variations over different periods. These detailed analytics currently are synthesized live in the administrative console and dissemination is therefore not available to public. However, the system enables users to freely access to anonymized, geocoded datasets, which can be utilized by researchers for the analysis. By integrating data collection, basic analytics, and data dissemination for users within a single framework, the application aims to strengthen the foundational data infrastructure required for disaster-related research.

The system also incorporates privacy-preserving mechanisms to ensure that user identities remain protected while retaining the analytical value of the collected data. Thus, this work establishes a structured bridge between citizen-generated observations and research-oriented data systems, improving the availability of high-resolution hazard data in India and enabling its effective use for spatial analysis, informed decision-making, and future research applications.

2. System Architecture and App Design of HazWatch

HazWatch is implemented as a multi-layered geospatial information system that integrates user interaction, crowdsourced hazard data acquisition, spatial visualization, backend processing, and administrative governance. The architecture supports both real-time reporting of ongoing events and retrospective reporting of past incidents, provided that spatial location and supporting evidence (e.g., images) are available. This enables continuous, temporally distributed data collection and improves the representativeness of hazard occurrence patterns. The system comprises two principal components: (i) a user-facing mobile interface for hazard reporting and visualization, and geocoded data retrieval, and (ii) an administrative console responsible for data management, moderation, analytics, and controlled data dissemination.

2.1 Home Dashboard and Spatial Interface

The Home interface functions as the primary interaction layer, integrating environmental context, participation metrics, and geospatial visualization within a unified dashboard (Fig. 1c). Key weather variables, including temperature, precipitation, and wind speed, are displayed to provide situational context. Platform engagement indicators—such as total reports, active contributors, and state-level coverage—are presented to reflect participation dynamics.

The core component is an interactive geospatial map that visualizes all submitted hazard events using their geocoded locations. The interface also supports multi-scale navigation and hazard-type filtering, enabling targeted spatial exploration, one touch informational balloon pop-up on the map area. A leaderboard section highlighting top three contributors is included to incentivize participation and reinforce the citizen-science framework.

2.2 Multi-Stage Hazard Reporting Module

Hazard reporting is implemented as a structured, multi-stage workflow to ensure standardized data acquisition (Fig. 2a-e). Users initiate reporting by selecting hazard type and affected area(s), followed by specification of the incident date (Fig. 2a). Geographic location is then defined using one of three input modes: automatic GPS capture, interactive map-based selection (the incidents point only within official Indian boundary can be located), or manual coordinate entry (Fig. 2b). User can hit “Go to coordinates” button to fly map to the inserted coordinate location. Media evidence is subsequently attached via camera capture or gallery upload (Fig. 2c-d). A final review stage allows verification and modification prior to submission (Fig. 2d). At any stage, users may store incomplete entries as drafts. Drafts are maintained separately, are accessible only through the profile interface, and are excluded from visualization and analysis. Importantly, accessing the reporting module from the navigation panel initializes a new form, ensuring that draft resumption is explicitly user-driven.

Additionally, users retain full control over their data, with the ability to delete both submitted reports and saved drafts at any time through the profile section.

2.3 User Interaction and Information Modules

This includes a dedicated Guidelines section designed to assist users in accurately reporting hazard events (Fig. 1a-h). This section displays login and signup page (Fig. 1a-b), clear guidelines on safe reporting practices (Fig. 1h), appropriate data entry, and correct selection of hazard categories and affected areas. In addition, the application incorporates an About section that serves as a centralized interface for platform information, support, and legal awareness.

This section presents the platform's mission(and vision, provides details about the team, and includes user support features such as Contact Us and Report Problem. It also contains key legal and policy documents, including the Privacy Policy, Terms of Use, and Copyright information. Together, these components ensure transparency, clearly communicate the purpose and scope of the platform, and inform users about their rights, responsibilities, and safe usage practices while interacting with the application.

2.4 User Profile and Data Management Module

The Profile section functions as a centralized interface for user-specific data management and application settings (Fig. 1i-l). It incorporates a structured data access mechanism through which users can edit report drafts or delete submitted reports (Fig. 1j) or request geocoded incident datasets (Fig. 1k) Each request undergoes an approval process to ensure data governance and privacy compliance, with request status (approved, rejected, or under review) transparently displayed within the "My Requests" interface (Fig. 1l) Approved datasets are made available for download, facilitating controlled dissemination of anonymized data for research and analytical purposes.

The module also supports profile management and application-level settings, including editable user information, password modification, while registered email address remains fixed as a unique user identifier language selection (Hindi/English), appearance preferences (light/dark mode), and account-level actions such as logout and account deletion (Fig. 1i).

2.5 Administrative System and Governance Framework

The administrative subsystem functions as a centralized governance layer responsible for data quality control, user moderation, and analytical management. Access is restricted through a fixed administrative authentication mechanism. The system adopts a post-submission moderation approach, wherein submitted reports are used to generate the analytics for spatio-temporal trend assessment (Fig a), and are continuously reviewed and managed reported problems are visualiszed and managed. Reports identified as erroneous, redundant, or inconsistent may be removed, and limited corrections—primarily related to geographic attributes in cases of reverse geocoding inconsistencies—are performed when necessary (Fig. 3b).

A communication module enables handling of user-submitted queries and reported issues (Fig. 3c-d). User management tools support monitoring of participation and administrative actions such as account

suspension or deletion (Fig. 3e). A data request management system governs external access to datasets through an approval-based workflow (Fig. 3f). Additionally, a content management component allows dynamic updating of legal and informational text (Fig. 3g). Lastly, in the settings section admin has control over his profile display, password, profile photo etc. (Fig. 3h).

3. Methodology: System Implementation and Data Workflow

The methodological framework of HazWatch was designed to integrate citizen science–based hazard reporting with geospatial data processing, visualization, and administrative governance within a unified mobile platform. The system combines mobile data acquisition, real-time spatial interaction, backend processing, and structured database management to support standardized collection and analysis of multi-hazard information across India (Fig. 4).

3.1 User Authentication and Account Management

The system implements user authentication using Firebase Authentication, which enables secure registration and login through email-based verification. Users provide basic demographic information during onboarding, which is stored in the backend and linked to their reporting activity. Email verification is supported through Firebase's built-in email service, which provides a free-tier quota for sending verification emails.

3.2 Weather Data Integration

Real-time environmental parameters such as temperature, precipitation, and wind speed are retrieved using the Open-Meteo API. The API provides current weather conditions based on geographic coordinates, allowing contextual environmental information to be displayed on the home dashboard.

3.3 Map and Geospatial Interface

The application uses OpenStreetMap as the base map layer for spatial visualization. The map interface supports interactive features such as zooming, panning, and marker placement for hazard reporting.

In addition, satellite imagery and street view layers are integrated using external map tile services (ESRI and Mapillary), enabling users to switch between standard and satellite or street views for improved spatial context.

3.4 Location Capture and Spatial Constraint

Hazard locations are captured through multiple input methods, including GPS-based automatic detection, interactive map selection, and manual latitude–longitude entry. To ensure geographic relevance, the reporting interface is restricted to India using a predefined GeoJSON boundary. Users can only select or pin locations within this boundary, preventing invalid spatial entries.

3.5 Reverse Geocoding

Once geographic coordinates are obtained, reverse geocoding is performed using API-based service i.e., Mapbox. The resulting administrative attributes (state and district) are stored in the backend database to avoid repeated API calls for identical or nearby coordinates. This caching mechanism reduces API dependency, improves response efficiency, and mitigates rate-limit constraints.

3.6 Hazard Data Collection and Processing

Users submit structured hazard reports containing attributes such as hazard type, affected area category, date of occurrence, and optional descriptions, along with photographic evidence. The system supports both real-time reporting and retrospective reporting of past incidents, provided that spatial location and supporting media are available. Each report is processed into a standardized geospatial record, combining spatial coordinates with attribute data for downstream storage and analysis.

3.7 Backend and Database Management

The backend is implemented using FastAPI, which handles API requests, data processing, and communication between the frontend and database. All report data, user information, and metadata are stored in MongoDB, a NoSQL database suitable for handling semi-structured geospatial data. Images associated with reports are stored as linked media resources within the system. Submitted reports remain subject to administrative review, ensuring progressive data quality improvement.

3.8 Data Visualization and Insight Generation

Stored reports are retrieved from the backend and visualized on the map using their geocoded locations. The system generates basic analytical outputs, including hazard frequency, spatial distribution, state-level coverage, and user participation metrics. These insights are presented through the dashboard and map interface.

3.9 Data Access and Privacy

Users can request access to anonymized geocoded datasets through the application. Approved datasets exclude personal identifiers such as name, email, and contact details, while retaining spatial and hazard-related attributes. This ensures compliance with privacy standards while supporting research and analysis.

3.10 App Code-Level Architecture

At the code level, HazWatch follows a client–server architecture in which the mobile application frontend communicates with backend APIs for authentication, report submission, data retrieval, image handling, and administrative operations. The frontend is developed using React Native with Expo Router, enabling cross-platform mobile deployment and structured screen-based navigation.

The application interface is organized into major user-facing modules, including Home, Report, Guidelines/About, Profile. Each module interacts with backend endpoints through API calls. User authentication is managed through Firebase Authentication, while user profile information, hazard

reports, draft records, data requests, and administrative records are stored in the backend database MongoDB.

The backend is implemented using FastAPI, which exposes RESTful API endpoints for report creation, report retrieval, user profile management, draft handling, data-request processing, and admin-level operations. MongoDB is used as the primary NoSQL database because it supports flexible storage of semi-structured records, including user attributes, hazard details, coordinates, timestamps, administrative location fields, and media references.

The report submission workflow passes through multiple code-level layers. First, the frontend collects structured form inputs, including hazard type, affected areas, incident date, location coordinates, and image data. To optimize database storage and reduce upload overhead, submitted incident images were compressed on the client side before storage in MongoDB. Multiple JPEG compression levels were visually evaluated to ensure that critical hazard evidence and contextual details remained clearly interpretable after compression (Fig. 5).

Based on qualitative assessment of image clarity and file size trade-offs, a moderate compression setting was adopted, resulting in images typically below 500 KB while preserving sufficient visual quality for hazard verification and spatial interpretation. This approach significantly reduced storage requirements without substantial degradation of evidential content.These inputs are validated on the client side and then sent to the backend through API requests. The backend processes the submitted data, performs reverse geocoding to derive state and district information, stores the report in MongoDB, and returns the saved record to the frontend for map visualization and user report history.

Spatial interaction is handled through map components using OpenStreetMap-based map tiles and optional satellite layers from ESRI Satellite and Mapillary. Location input is constrained using the predefined boundary of India in GeoJSON, ensuring that users can select or pin only valid locations within India. The resulting coordinates are stored in degree decimals with each report and used for map markers, dashboard statistics, district coverage, and spatial filtering.

Images uploaded during reporting are stored as linked media resources associated with each report record. Draft reports are stored separately from submitted reports, ensuring that only active submitted reports appear on the public map and dashboard analytics. Administrative functionalities are implemented through protected backend endpoints, enabling privileged operations such as report moderation, user management, data request handling, and controlled dataset generation. These operations are restricted through a fixed administrative authentication mechanism, ensuring secure separation between user-level and admin-level access.

Overall, the code-level architecture connects frontend modules, authentication services, geospatial APIs, reverse geocoding, backend processing, database storage, and map-based visualization into a unified hazard-reporting system.

4. Discussion

The HazWatch platform represents an applied integration of citizen science and geospatial technologies, demonstrating how distributed user participation can be systematically harnessed to generate structured hazard datasets. By embedding reporting functionality within a mobile-based geospatial interface, the system enables direct capture of hazard events at the point of occurrence. This approach fundamentally shifts data generation from centralized institutional mechanisms toward a decentralized, user-driven model, thereby increasing the immediacy and spatial specificity of recorded events.

A key aspect of the system is the transformation of raw user inputs into standardized geospatial records. The multi-step reporting workflow enforces consistency through predefined hazard categories, affected area classifications, and spatial inputs, ensuring that each submission adheres to a uniform structure. This standardization is critical for enabling meaningful spatial aggregation and comparative analysis across regions. The integration of coordinate-based inputs with reverse geocoding further enhances the analytical value of the data by linking point-level observations to administrative units such as districts and states, facilitating multi-scale spatial interpretation.

The geospatial interface serves as both a data collection and visualization environment, allowing users to interact with reported hazards in a spatially explicit manner. The use of an interactive map enables dynamic exploration of hazard distribution, supporting the identification of spatial patterns and clusters. The ability to filter hazards by type further refines this interaction, allowing focused examination of specific hazard categories. In this context, the map is not only a visualization tool but also a means of reinforcing spatial awareness among users, which is central to the participatory nature of the platform

The integration of environmental context within the dashboard adds an additional analytical dimension to the system. This co-representation of hazard and meteorological data enables users to interpret events within their immediate climatic context.

At the interface level, the modular organization of the application, comprising Home, Report, informational sections, and Profile-supports offer clear functional segmentation while maintaining integration across components. Each module contributes to a specific aspect of the data ecosystem, from data generation and visualization to user management and data access. The inclusion of a data request mechanism extends the functionality of the platform beyond user interaction, enabling the extraction of structured datasets for external use in spatial analysis and research contexts.

The incorporation of participation-based features such as contributor recognition introduces a feedback mechanism within the system, linking user activity with visible acknowledgment. This not only reinforces engagement but also contributes to sustained data generation, which is essential for maintaining the temporal continuity of the dataset. At the same time, the presence of informational and legal interfaces ensures that users interact with the platform within a clearly defined framework of purpose, usage guidelines, and data governance.

The HazWatch system operates as an integrated geospatial data framework in which user participation, data visualization and spatial data access are interconnected through a unified architecture. The platform offers a cost-effective mobile-based geospatial systems which is designed to capture, structure, and present hazard information in a manner that is both user-driven and analytically relevant.

5. Conclusion

The HazWatch platform demonstrates the successful development and implementation of a geospatial, citizen science–based system for multi-hazard data collection and analysis, and distribution in India. By integrating mobile-based reporting, geospatial processing, and structured data management within a unified framework, the system establishes an effective mechanism for capturing hazard information at fine spatial and temporal scales.

The application enables users to contribute hazard observations through a standardized reporting workflow, ensuring consistency and usability of the collected data. In addition to data collection, the platform extends its functionality to include data accessibility through anonymized dataset sharing, thereby supporting research and analytical applications. The system also incorporates user-centric features such as participation tracking and contributor recognition, reinforcing sustained engagement within the citizen science framework.

Overall, HazWatch establishes a functional link between field-level observations and structured geospatial data systems. It provides a scalable foundation for developing high-resolution hazard datasets and supports the broader objective of improving data availability for disaster-related research and spatial analysis in India.

6. Limitations

Despite its functional design and integrated data workflow, the HazWatch platform is subject to several practical limitations inherent to citizen science–based systems and resource-constrained implementations.

A primary limitation Is related to user participation, as the platform relies on voluntary public contributions. Reporting activity may vary across regions and time periods, leading to uneven spatial and temporal data coverage.

The accuracy and reliability of reported information remain a concern due to two factors: variability in user understanding, which may affect both spatial and categorical accuracy, and the inherent limitations of mobile GPS, which can introduce positional errors despite guided reporting workflows.

Financial and operational constraints further limit system scalability and performance. As a research-driven initiative, restricted funding affects the integration of advanced APIs, database expansion, and deployment of high-efficiency server infrastructure.

These limitations reflect broader challenges associated with citizen-driven geospatial systems in diverse and resource-constrained environments, highlighting the need for continued refinement and support mechanisms.

Declarations

Authors' Contributions

ZK: Conceptualization; Methodology; Software; System design; Data curation; Visualization; Writing – review & editing. DV: Writing – original draft; Writing – review & editing; Beta testing and feedback. AK: Writing – review & editing; Beta testing and feedback.

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The authors declare that no external funding was received for the development of the HazWatch application, the preparation of this manuscript, or the current maintenance of the platform. The initiative is presently self-supported; however, future expansion, scaling, and long-term sustainability may involve support.

Competing Interest

The authors declare that they have no competing financial or non-financial interests. No external funding was received for this study, and the work was conducted independently.

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Data Availability Statement

This manuscript primarily describes the design, architecture, and implementation of the HazWatch mobile application and does not rely on externally analyzed experimental datasets. No publicly archived dataset was generated or analyzed specifically for this study. Due to system security, privacy, and ongoing development considerations, the application source code and backend infrastructure are not publicly distributed.

Declaration of AI Use: During the preparation of this manuscript, the author used ChatGPT 5.5 for improving language and readability. After using this tool, the authors reviewed, edited, and verified the content as needed. The authors take full responsibility for the conceptualization accuracy, originality, and integrity of the final work.

Intellectual Property Notice: The mobile application, including its source code, UI/UX design, and functional architecture, is the property of first and communicating author. Copyright © 2026. All rights reserved.

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Figures

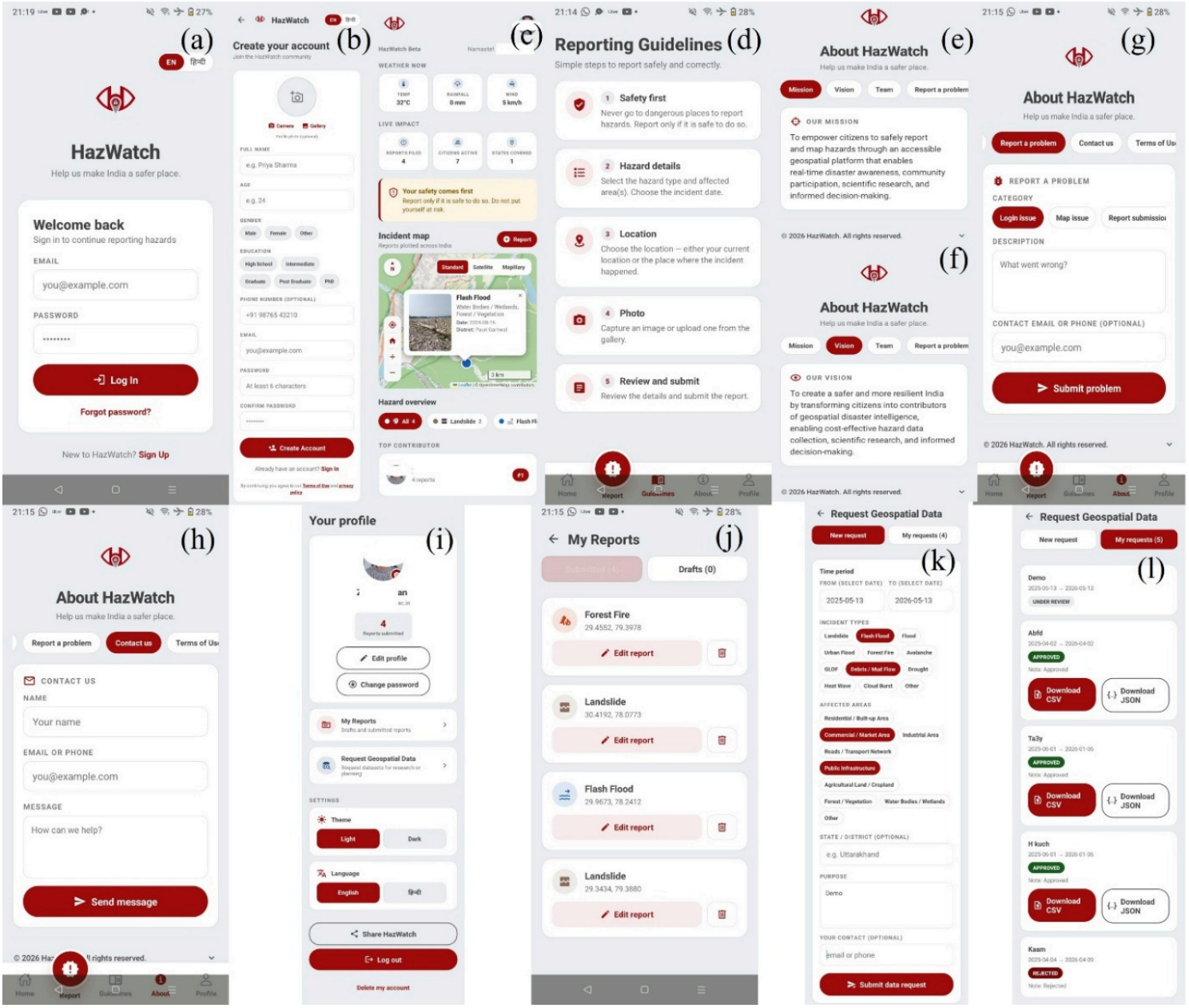


Figure 1

User interface and spatial interface (c); User Interaction and Information Modules (d-h); User Profile and Data Management Module (i-l)

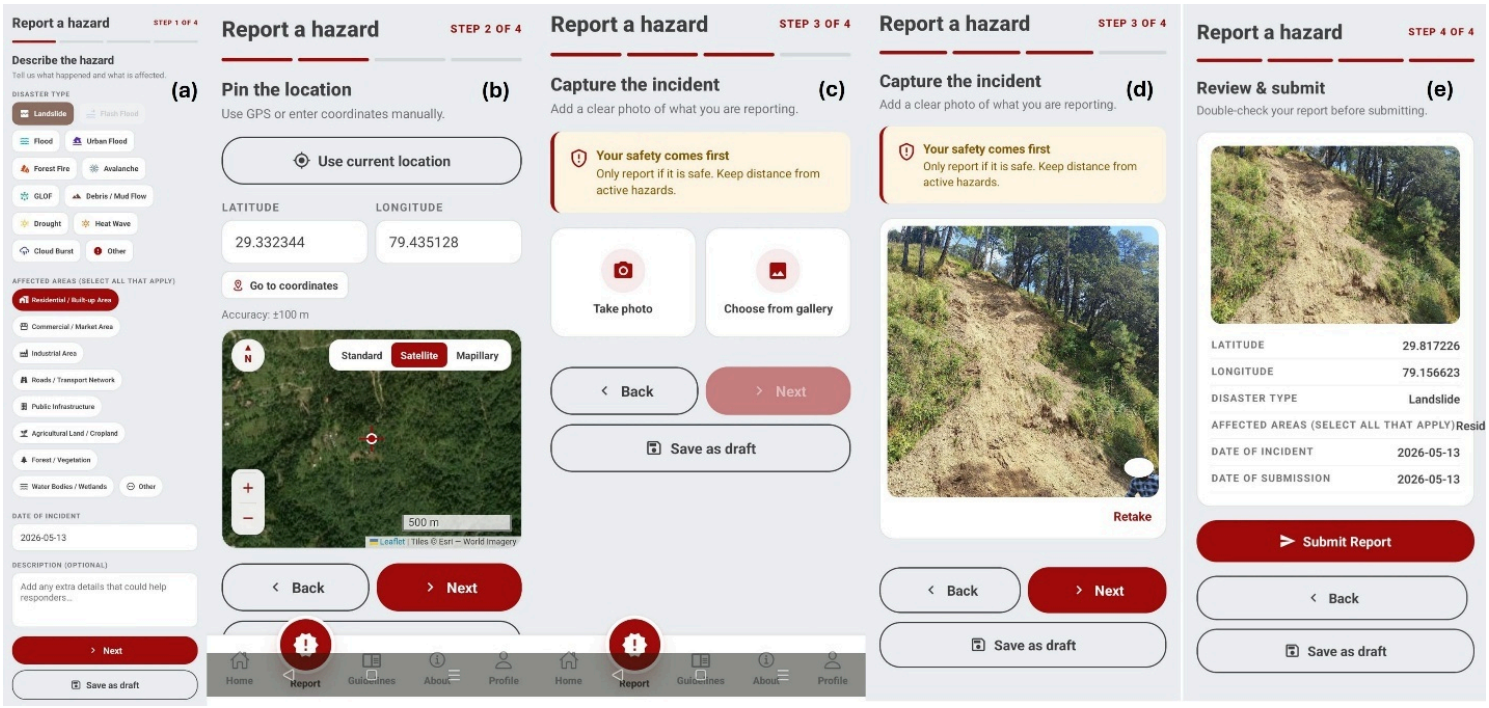


Figure 2

Multi-Stage Hazard Reporting Module (a-e)

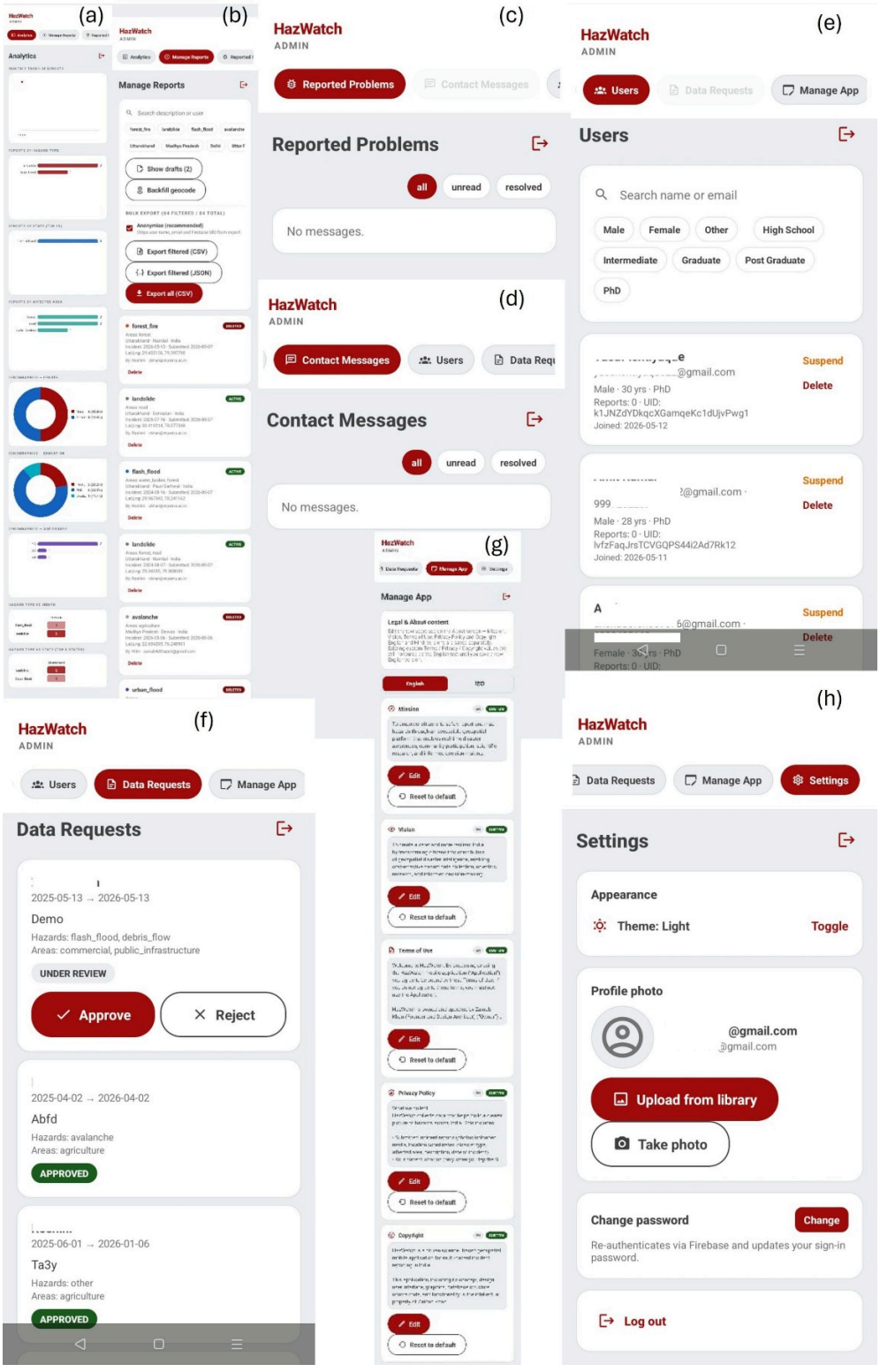


Figure 3

Administrative System and Governance Framework (a-h)

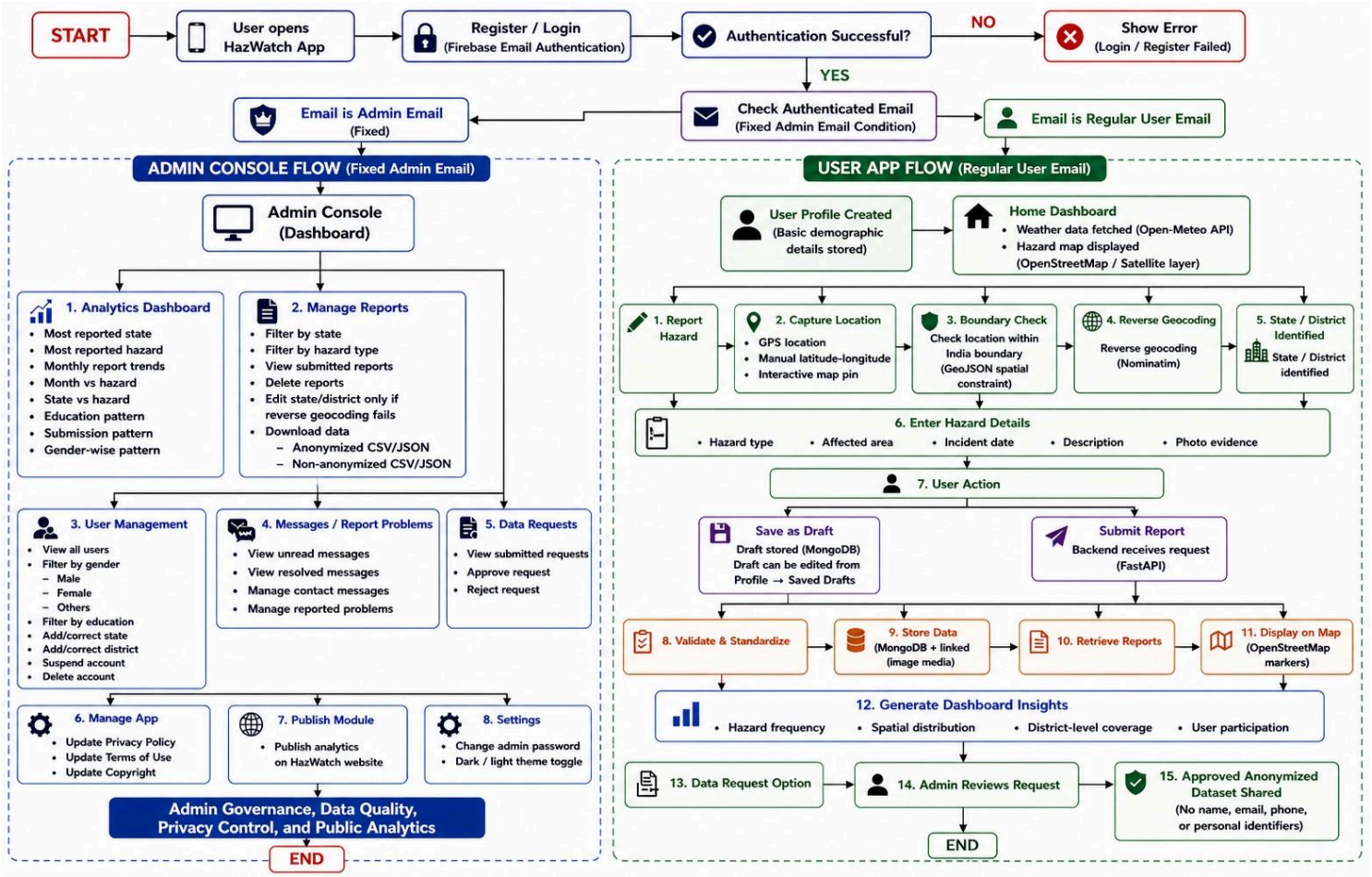


Figure 4

Methodological Flowchart

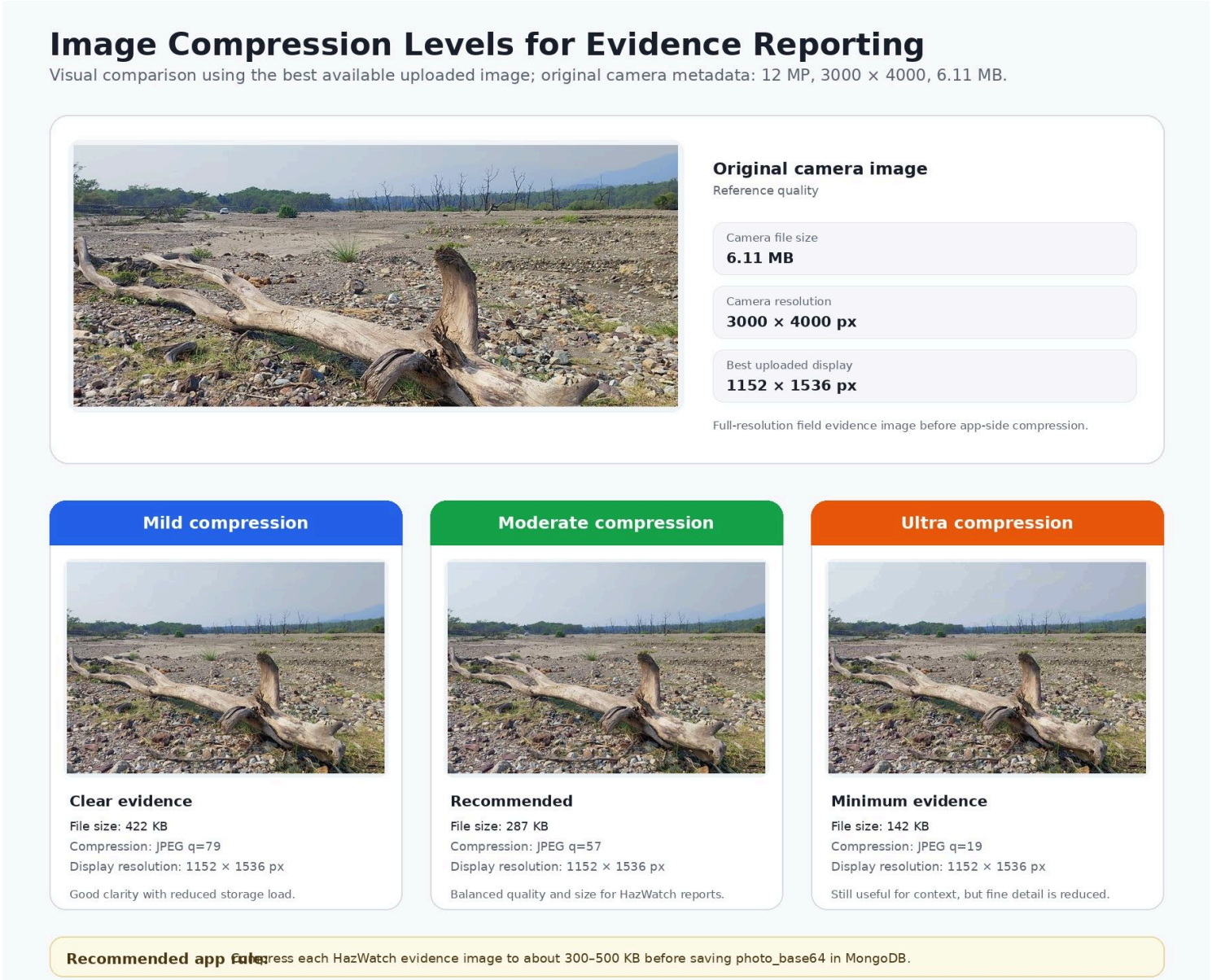


Figure 5

Visual comparison of progressive image compression levels used for assessing file size optimization, illustrating the balance between file-size reduction and preservation of evidential scene interpretability.