Proceedings Academic Universitas Jambi
Volume 2, Issue 3, September, 2026

Development of a Spatial-Based Forestry Patrol Information System (GIS) to Overcome Obstacles to the Performance of Protected Forest Supervision at the UPTD KPH Region V Aceh

Adam[1], Isnaini[2], Novita Wulandari[3], and Renny Candradewi Puspitarini[4]

[1]Department of Public Administration, Faculty of Social and Political Sciences, Universitas Medan Area, Medan, Indonesia
[2]Faculty of Law, Universitas Medan Area, Medan, Indonesia
[3]Department of Government Science, Universitas Tamansiswa Palembang, Palembang, Indonesia
[4]Department of Political Science, Faculty of Social and Political Sciences, Universitas Panca Marga, Probolinggo, Indonesia

Corresponding author email: adam@staff.uma.ac.id

Abstract

Forest damage in the UPTD KPH Region V Aceh due to illegal logging and land encroachment continues to occur due to weak preventive supervision aspects. Performance evaluations indicate multiple obstacles for 201 security personnel who must monitor an area of 295,053 hectares. Limited technical capabilities, minimal mastery of difficult terrain, communication delays, and patrol management that is still manual and reactive, mean that violations are often only detected after forest damage has occurred. As a tactical solution, this study aims to design and build a Spatial-Based Forestry Patrol Information System (GIS) as an intervention instrument to overcome individual, psychological, and organizational barriers of officers in the field. The research method used is the Design Science Research Methodology (DSRM) combined with a descriptive qualitative approach for system requirements analysis. Field data collection and analysis were conducted through participatory observation, in-depth interviews with forest rangers, rangers, and forestry extension workers, and a review of operational documents of the UPTD KPH Region V Aceh. Data validity was tested through source triangulation. The development of the information system was built using the Waterfall method which includes the stages of requirements analysis, software architecture design (system design), coding (implementation), testing, and implementation. The output of this research is an operational information system product (Android-based mobile application for field officers and a web-based dashboard for KPH management). This information system is equipped with the following main features: (1) Digital Mapping & Offline Spatio-Temporal Tracking (GIS) for navigation and recording of violation coordinates in real-time without relying on internet signals; (2) Integrated Dispatch & Alert System as a digital standard operating procedure (SOP) to accelerate cross-resort communication; and (3) Patrol Resource Management Module for transparency of budget governance based on officer patrol GPS history logs. The implementation of this system contributes to changing the monitoring pattern from reactive to integrated preventive, optimizing the limited tactical capacity of personnel, and providing a measurable forest encroachment mitigation scheme at the site level.

Keywords: Geographic Information System (GIS); Forestry Patrol; Performance Evaluation; Protected Forest Monitoring; Aceh Region V.

© 2026 The Author(s). Published with license by LPPM Universitas Jambi. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International (CC BY 4.0 International). This license enables reusers to distribute, remix, adapt, and build upon the material in any medium or format, so long as attribution is given to the creator.

Proceedings Academic Universitas Jambi
Volume 2, Issue 3, September, 2026

Cite This Article

Adam, Isnaini, Novita Wulandari, and Renny Candradewi Puspitarini. (2026). Development of a Spatial-Based Forestry Patrol Information System (GIS) to Overcome Obstacles to the Performance of Protected Forest Supervision at the UPTD KPH Region V Aceh. Proceedings Academic Universitas Jambi, 2(3): e59998. DOI: 10.22437/proca.v2i3.59998

Editor

Dr. Kevin Waldo, M.Pd.

Article info

Received: August 4, 2026 . Revised: August 26, 2026 . Accepted: September 1, 2026

© 2026 The Author(s). Published with license by LPPM Universitas Jambi. This is an open-access article distributed under the terms of the Creative Commons Attribution 4.0 International (CC BY 4.0 International). This license enables reusers to distribute, remix, adapt, and build upon the material in any medium or format, so long as attribution is given to the creator.

INTRODUCTION

Forests are strategic natural resources that maintain ecosystem balance, regulate water, store carbon, and sustain biodiversity (Kelode, 2025). In Indonesia, forests also support community livelihoods and regional economies. However, forest degradation continues through illegal logging, land conversion, and encroachment. The Aceh Region V Forest Management Unit (Unit Pelaksana Teknis Daerah Kesatuan Pengelolaan Hutan / UPTD KPH Wilayah V Aceh) manages approximately 295,053 hectares of vital forest areas. The illegal logging and the conversion of protected forest into coffee plantations remain persistent threats. These violations are frequently detected only after severe environmental damage has already occurred, highlighting a critical gap in the organization's capacity to perform preventive surveillance rather than reactive enforcement. Forest degradation and deforestation in Aceh are rarely isolated events; instead, they are most clearly indicated by the dramatic increase in severe hydrometeorological disasters (like flash floods and landslides) that occur when the region's natural ecological defenses are compromised. The most definitive and catastrophic indicator of this crisis occurred during the devastating flash floods and landslides of late November to December 2025. Triggered by extreme rainfall from Tropical Cyclone Senyar, the disaster resulted in more than 1,000 fatalities across Sumatra and displaced nearly a million residents("As Aceh Reels from Severe Floods, NTU-Led Study in 2024 Traces Roots to Forest Loss") .

The United Nations Conference at Stockholm convenes that the main root of this governance failure lies in a severe imbalance between available resources and the vast operational territory (Educational Foundation for Nuclear Science, 1972). For example, Indonesia only employs 201 forest security personnel deployed across four sub-units and nine resorts to monitor nearly 300,000 hectares of mountainous, steep, and poorly accessible terrain. According to Simamora's performance framework, their performance is severely constrained by three interrelated dimensions. Individual barriers include limited technical capability, poor terrain mastery, and lack of advanced navigation skills (Mandala, Kisman, Kanto, & Trisilo, 2025). Psychological barriers are characterized by high job-related stress and social pressure from local communities. Organizational barriers involve traditional monitoring equipment, lack of communication infrastructure, and administrative, non-transparent budget allocations for patrols. Isolated structural interventions, such as training without proper technical tools, have proven ineffective (Tanjung, Kusmanto, Isnaini, Adam, & Siregar, 2021). Therefore, there is an urgent need for an intervention that bridges these operational gaps by providing a concrete, tech-driven solution: a dedicated Spatial Information System.

To address this pressing managerial and ecological challenge, this study shifts from a purely conceptual evaluation to an action-oriented framework by designing, developing, and deploying a Spatially-Based (GIS) Forest Patrol Information System. By digitizing standard operating procedures (SOPs), optimizing patrol routes, and establishing a real-time tracking network, this technology directly targets the core vulnerabilities of field officers. It transforms the field operation from an analog, delayed, and reactive model into an automated, precise, and preventive green governance ecosystem. To guide the development and evaluation of this system, this study addresses three fundamental research questions. First, it investigates the specific system requirements and technical specifications of a forest patrol information system that can effectively mitigate the individual, psychological, and organizational performance barriers faced by officers in UPTD KPH Wilayah V Aceh. Second, it formulates how a spatially-based (GIS) mobile and web-integrated information system

architecture can be designed and developed to suit the complex topography and limited communication access of the Aceh Region V forest area. Third, it assesses to what extent the implementation of the developed information system improves early detection responses, patrol route optimization, and transparency in resources or budget management for forest protection.

Furthermore, this research provides multi-layered benefits across academic, practical, and institutional dimensions. For the institution of UPTD KPH Wilayah V Aceh, it equips management with an administrative dashboard to monitor the real-time movement of all 201 personnel, changing the command structure from guesswork to data-driven oversight. For the field personnel, including forest rangers and police, it reduces operational stress and individual limitations by providing digital maps and offline tracking tools, allowing safer and more efficient navigation through hazardous terrains. For policymakers and auditors, it enhances fiscal accountability by linking budget allocations directly to verifiable digital GPS patrol logs rather than easily manipulated manual reports.

Ultimately, this study offers significant contributions to the body of knowledge and public administration practices through several distinct pathways. As an artifact-driven solution under a design science contribution, this study moves beyond traditional public administration studies that merely identify field limitations and offer abstract policy suggestions by providing a tangible, functional software artifact specifically customized for remote forest governance. In terms of interventions in the causal chain of deforestation, this research disrupts the traditional failure cycle of forest protection, which typically spans from low capability and low patrol frequency to high encroachment, by injecting digital optimization that shifts the operational paradigm toward automated early warnings. Finally, it offers a methodological interdisciplinary bridging by providing a new empirical framework that successfully merges qualitative public management analysis with Design Science Research Methodology (DSRM) from computer science, creating a robust, cross-disciplinary approach to environmental protection.

Forest monitoring has increasingly evolved from conventional field patrols toward digital and spatially enabled monitoring systems. Numerous studies have demonstrated that Geographic Information Systems (GIS), remote sensing, mobile technologies, and spatial decision support systems can significantly improve forest surveillance by increasing the speed and accuracy of environmental monitoring (Loomis, de Araújo e Souza, Angel, & Fabbri, 2024; Packalen et al., 2013; White et al., 2016). Many digital forestry applications remain technically sophisticated but inadequately aligned with the actual needs of field officers responsible for conservation enforcement. The operational challenges faced by forest management institutions illustrate this limitation. In the conservation forests of Aceh, monitoring activities are constrained not only by geographical complexity but also by limited navigation capability, poor communication infrastructure, fragmented reporting mechanisms, delayed information exchange, and insufficient transparency in operational resource management (Tanjung et al., 2021). These multidimensional problems indicate that forest monitoring is not merely a technological issue but also an organizational and socio-technical challenge. Therefore, developing an effective information system requires an approach capable of integrating user requirements, organizational processes, and technological innovation into a single research framework.

Design Science Research Methodology (DSRM) has become one of the most widely and alternatively accepted paradigms for developing innovative information systems intended to solve complex organizational problems (Peffers, Tuunanen,

Rothenberger, & Chatterjee, 2007). Unlike conventional software engineering approaches that primarily focus on system construction, DSRM emphasizes the creation of scientifically grounded artifacts that simultaneously contribute practical solutions and theoretical knowledge. According to Hevner et al. (2004), Design Science positions information systems research as an engineering discipline in which knowledge is generated through the design, implementation, and rigorous evaluation of artifacts capable of addressing real-world organizational problems. Peffers et al. (2007) further operationalized this paradigm into six systematic stages consisting of problem identification, objective definition, design and development, demonstration, evaluation, and communication. This structured process ensures that every technological component originates from empirically identified organizational needs and is validated through iterative evaluation.

Recent studies have reinforced the relevance of DSRM in software engineering and digital transformation research. Peffers et al. (2008) expanded the DSR process by demonstrating how research artifacts can be systematically produced and presented while maintaining scientific rigor throughout the development lifecycle. Similarly, Engström et al. (2020) argued that contemporary software engineering research naturally aligns with Design Science because both disciplines emphasize iterative artifact construction, empirical validation, and continuous refinement based on stakeholder feedback. Rather than treating software merely as a technical product, Design Science recognizes software as a knowledge artifact whose value is demonstrated through its ability to solve organizational problems.

The application of DSRM is also increasingly recognized in sustainability-oriented information systems. Brooks (2020) demonstrated that Design Science provides an effective framework for translating sustainability objectives into system requirements through systematic requirement elicitation and iterative design processes. This capability is particularly relevant for environmental governance because sustainability problems are inherently interdisciplinary, involving ecological preservation, institutional coordination, public accountability, and technological innovation simultaneously. Consequently, DSRM enables environmental information systems to address not only technical functionality but also governance effectiveness.
Despite these developments, an important research gap remains within the domain of digital forestry management. Existing studies on GIS-based forest monitoring generally focus on spatial analysis, remote sensing, drone surveillance, or deforestation detection (Szafarczyk & Agbasi, 2025), whereas relatively few studies integrate qualitative organizational analysis with Design Science to develop operational information systems specifically designed for forest patrol activities. Furthermore, previous systems frequently rely on continuous internet connectivity, centralized reporting mechanisms, or desktop-based GIS platforms, making them less suitable for remote forest environments where communication infrastructure is unreliable. Limited attention has also been given to offline spatial data collection, automated synchronization, integrated patrol management, and transparent operational budget monitoring within a unified digital platform.

This study addresses these limitations by integrating qualitative inquiry with Design Science Research Methodology to develop a Spatial-Based Forestry Patrol Information System specifically designed for the operational context of UPTD KPH Region V Aceh. Unlike previous research that primarily evaluates existing technologies, this study systematically transforms organizational barriers identified through field observations, interviews, and document analysis into software requirements and subsequently into a validated digital artifact. The integration of

qualitative requirement analysis, GIS technology, offline-first mobile computing, spatial databases, and iterative system evaluation represents a comprehensive socio-technical approach that bridges the gap between organizational needs and digital innovation.

The methodological contribution of this research lies in demonstrating how DSRM can be effectively integrated with qualitative descriptive analysis to support the development of digital governance systems in the forestry sector. Rather than employing qualitative methods solely for contextual understanding, this research uses qualitative findings as the primary mechanism for generating artifact requirements, thereby extending the practical application of Design Science within environmental governance research. The practical contribution is reflected in the development of a dual-platform GIS patrol ecosystem capable of supporting offline field operations, real-time spatial monitoring, integrated patrol coordination, and transparent operational management. By directly addressing the organizational, technological, and geographical constraints experienced by forest officers, the proposed system is expected to improve monitoring effectiveness, accelerate decision-making processes, strengthen institutional accountability, and ultimately contribute to more sustainable forest conservation practices.

METHODS

This study employed an interdisciplinary methodology that combined a qualitative descriptive approach with the Design Science Research Methodology (DSRM) to create a tech-driven solution for forest protection. Damage to conservation areas due to community economic activities is a major challenge in forest monitoring in Aceh. Previous research in Putri Betung District, Gayo Lues Regency, showed that the expansion of citronella plantations triggered 3.92% of deforestation in the Gunung Leuser National Park (TNGL) area during the 2020–2021 period. Land conversion and rampant illegal logging to meet the demand for firewood for citronella oil distillation have triggered a chain of impacts, ranging from water resource crises and erosion to flooding. This high rate of damage confirms that conventional monitoring methods are no longer adequate. Therefore, current research on the development of a Spatial-Based Forestry Patrol Information System (GIS) at the UPTD KPH Region V Aceh presents a strategic solution to overcome the limitations of field monitoring and accelerate the response to mitigate these environmental impacts (Tanjung et al., 2021). The qualitative approach was utilized to analyze the requirements and institutional barriers within the natural setting of the Aceh Region V Forest Management Unit (UPTD KPH Wilayah V Aceh). Meanwhile, DSRM structured the iterative design, development, and evaluation of the digital software artifact. The research was conducted within the expansive 295,053-hectare operational territory of UPTD KPH Wilayah V Aceh, focusing on hot spots prone to illegal logging and illegal land conversion into coffee plantations. Primary data regarding field operational barriers were gathered from 201 forest security personnel, including forest police officers, forest rangers, forestry extension workers, and management personnel. Informants were selected purposively based on their active involvement in field supervision, and the validity of the collected data was verified using source triangulation.

The systems development lifecycle followed a structured Waterfall model, which began with a rigorous requirements analysis phase. In this phase, qualitative data from participant observations, in-depth interviews, and operational document reviews were reduced and categorized using Simamora's performance framework to map specific field vulnerabilities into technical requirements. The individual,

psychological, and organizational barriers identified—such as weak navigation skills, low field motivation, traditional monitoring equipment, and non-transparent budget tracking were directly translated into necessary software features. These features included an offline spatial tracker, an integrated dispatch mechanism, and a transparent digital budget log. The system architecture was designed as a dual-platform green governance ecosystem, comprising a mobile application for field rangers and a comprehensive web-based management dashboard for KPH administrators.

This study employed an interdisciplinary research design by integrating a qualitative descriptive approach with the Design Science Research Methodology (DSRM). The qualitative component was used to explore operational problems, institutional constraints, and user requirements within forest protection activities, whereas DSRM guided the systematic development and evaluation of a digital artifact in the form of a Spatial-Based Forestry Patrol Information System. This integration enabled the research to simultaneously generate practical solutions and theoretical contributions in digital environmental governance. The research was conducted within the 295,053-hectare operational jurisdiction of UPTD KPH Region V Aceh, Indonesia. The area includes protected forests, limited production forests, and regions adjacent to Gunung Leuser National Park that experience frequent illegal logging and agricultural encroachment.

Table 1 How Design Science Research Methodology (DSRM) is implemented

DSRM Stage	Activities	Output
Problem Identification	Analyze patrol barriers	Problem definition
Define Objectives	Determine system goals	Design objectives
Design and Development	Build GIS system	Software artifact
Demonstration	Pilot implementation	Operational prototype
Evaluation	Functional testing + UAT	Performance evidence
Communication	Documentation and publication	Scientific contribution

Source: modified from Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). and Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information Systems Research. MIS Quarterly, 28(1), 75–105.

RESULTS

DSRM is an iterative method. This method does not have to be strictly sequential but rather uses a logical flow approach. Several things are done when using this method: First, there is identification of the problem and motivation. In this case,

initial research has been carried out because there are serious challenges for forest rangers to carry out forest inspections over very large areas. Apart from that, forest rangers also have to deal with budget management which must be efficient and effective. In fact, it is not uncommon for them not to get a decent salary. This then makes the rangers have low motivation to carry out their duties. Not to mention that they have to deal with the forest mafia and policy makers and implementers at the center who tend to ignore aspects of good forest governance.

The following is a preliminary plan for research and development of a GIS-based forest patrol information system using DSRM.

Rencana Proyek: GIS-Based Forest Patrol Information System

```
1 # Project: GIS-Based Forest Patrol Information System
2
3 ## Objective
4 Develop a GIS-powered dashboard for forest patrols to improve real-time
  monitoring and incident reporting, following the DSRM framework.
5
6 ## Key Files & Context
7 - Dashboard structure will be designed in HTML/CSS/JS.
8 - Integration will involve a lightweight JS mapping library (e.g.,
  Leaflet).
9 - No backend is required at this prototyping stage.
10
11 ## Implementation Steps
12 1.  **Requirement Definition:** Map specific dashboard features to DSRM
  objectives.
13 2.  **Dashboard Prototype (Front-end):**
14     - Create HTML skeleton.
15     - Style with CSS.
16     - Integrate Leaflet.js for maps.
17 3.  **Data Mocking:** Define JSON structures for patrol
  locations/incidents.
18 4.  **Verification:** Validate UI responsiveness and map interactivity.
19
20 ## Verification & Testing
21 - User review of the dashboard mock-up.
22 - Functional test of map interactivity.
```

Gambar 1 Project Plan: GIS-Based Forest Patrol Information System
Source : Researchers, 2026

This section explains the preparatory planning which includes developing a GIS powered dashboard for forest rangers. Next are the following stages which are called evaluation parameters:

Parameter Evaluasi Teknis Dashboard

Untuk memastikan artifak (dashboard) memenuhi standar yang diharapkan, kita akan menggunakan metrik berikut:

1. **Map Load Time (Waktu Muat Peta):**
    * **Metode:** Mengukur durasi dari request hingga *tile* peta tampil sepenuhnya.
    * **Goal:** < 2 detik dalam jaringan 4G/Wifi standar.
2. **Incident Rendering Latency (Latensi Marker):**
    * **Metode:** Waktu yang dibutuhkan sistem untuk merender marker baru di peta setelah data JSON/API diperbarui.
    * **Goal:** < 500ms (agar *real-time* terasa instan).
3. **Responsiveness (Responsivitas UI):**
    * **Metode:** Pengujian menggunakan *Lighthouse* (Chrome DevTools) untuk memastikan tata letak dashboard adaptif di berbagai ukuran layar (Desktop, Tablet, Mobile).
    * **Goal:** Skor performa > 80 di semua kategori perangkat.
4. **Interactivity Success Rate (Tingkat Keberhasilan Interaksi):**
    * **Metode:** Persentase interaksi pengguna yang sukses (misal: klik marker menampilkan *popup*, klik *sidebar* memperbesar lokasi di peta).
    * **Goal:** 100% keberhasilan (tidak ada *error* pada *event handler*).

Figure 2 Dashboard Evaluation Parameters
Sumber : Research Analysis, 2026

The following are the technical testing parameters to add to DSRM research plan. These parameters will be used to evaluate the Evaluation phase of the methodology. The implemented section as follows:

Parameter Evaluasi Teknis Dashboard

Untuk memastikan artifak (dashboard) memenuhi standar yang diharapkan, kita akan menggunakan metrik berikut:

1. **Map Load Time (Waktu Muat Peta):**
    * **Metode:** Mengukur durasi dari request hingga *tile* peta tampil sepenuhnya.
    * **Goal:** < 2 detik dalam jaringan 4G/Wifi standar.
2. **Incident Rendering Latency (Latensi Marker):**
    * **Metode:** Waktu yang dibutuhkan sistem untuk merender marker baru di peta setelah data JSON/API diperbarui.
    * **Goal:** < 500ms (agar *real-time* terasa instan).
3. **Responsiveness (Responsivitas UI):**
    * **Metode:** Pengujian menggunakan *Lighthouse* (Chrome DevTools) untuk memastikan tata letak dashboard adaptif di berbagai ukuran layar (Desktop, Tablet, Mobile).
    * **Goal:** Skor performa > 80 di semua kategori perangkat.
4. **Interactivity Success Rate (Tingkat Keberhasilan Interaksi):**
    * **Metode:** Persentase interaksi pengguna yang sukses (misal: klik marker menampilkan *popup*, klik *sidebar* memperbesar lokasi di peta).
    * **Goal:** 100% keberhasilan (tidak ada *error* pada *event handler*).

Figure 3 Dashboard Technical Evaluation Parameters
Source : researchers, 2026

The implementation for the dashboard with forest locations in Aceh is carried out using the following command:

```
✓ Edit  dashboard.html → Accepted (+4, -4)

26
27        <script
      src="https://unpkg.com/leaflet@1.9.4/dist/leaflet.js"></script>
28        <script>
29 -          // Inisialisasi Peta
30 -          var map = L.map('map').setView([-2.5, 118.0], 5);
29 +          // Inisialisasi Peta (Aceh)
30 +          var map = L.map('map').setView([4.6, 96.7], 9);
31
      L.tileLayer('https://{s}.tile.openstreetmap.org/{z}/{x}/{y}.png',
      {
32                attribution: '© OpenStreetMap contributors'
33            }).addTo(map);
34
35 -          // Contoh Marker Incident
36 -          L.marker([-2.5, 118.0]).addTo(map).bindPopup('Incident in
     Sector A-1');
35 +          // Contoh Marker Incident (Aceh)
36 +          L.marker([4.6, 96.7]).addTo(map).bindPopup('Incident in
     Aceh Forest');
37        </script>
38    </body>
39    </html>
```

Figure 4: Determination of Aceh's Forest Locations in the DSRM
Source: Researchers 2026

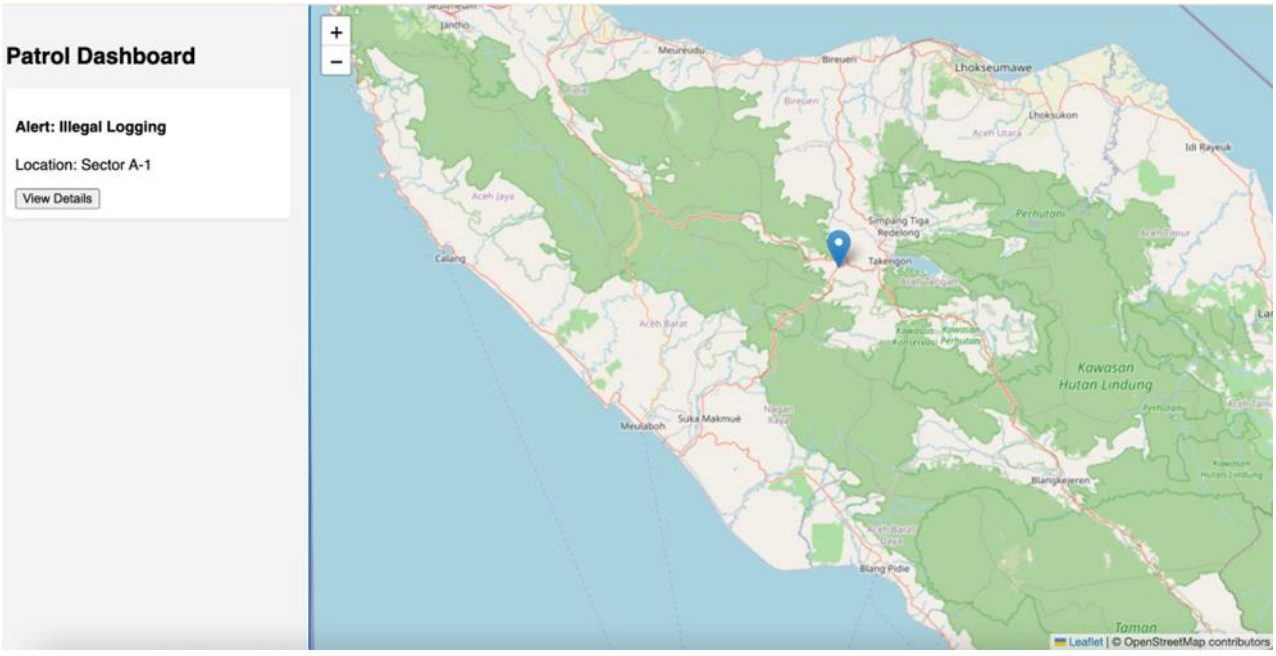

Figure 5: Visualization in Aceh's Forest Locations in the DSRM
Source: Researchers 2026

DISCUSSION

How the Artificial Intelligence using Laravel is implemented

The core application backend was developed using PHP 8.4 and the Laravel framework, leveraging its latest architectural enhancements for robust enterprise performance. The backend utilize Laravel's optimized Eloquent Object-Relational Mapping (ORM) and native database migration systems to model spatial data and user relations cleanly. For security, authentication and authorization were implemented using Laravel Sanctum to manage API tokens for the mobile application, alongside Role-Based Access Control (RBAC) to restrict features based on the officer's hierarchy (e.g., Administrator, Head of Sub-unit, and Resort Ranger). Database management relied on MySQL with the PostGIS extension to handle geospatial data smoothly, allowing the system to store intricate polygonal data representing protected forest boundaries, limited production forests, and detected encroachment zones.

The frontend architecture was split into two components to match operational realities in the field. The administrative dashboard was built as a responsive web interface using Laravel Blade templates integrated with Tailwind CSS and Livewire, providing a real-time reactive user experience without complex JavaScript frameworks. This dashboard featured an interactive web map powered by Leaflet.js, which connected to OpenStreetMap and satellite imagery to display overlapping spatial data layers. For field operations, a lightweight progressive hybrid mobile application was developed to communicate with Laravel's RESTful API endpoints. The mobile app utilized SQLite for local data persistence, allowing rangers to record patrol tracks, pin GPS coordinates of illegal logging activities, and log field observations entirely offline while navigating remote areas with zero cellular coverage.

System integration and automated synchronization protocols were established to handle data transmission once field officers regained internet access. When the mobile app reconnected to a network, it automatically synchronized its queued local SQLite logs with the central MySQL database via an optimized POST /api/v1/patrol/sync endpoint in Laravel. To ensure system reliability and data integrity, the system underwent rigorous testing using a dual-layered approach. Functional testing was executed through Laravel's built-in testing suite, leveraging PHPUnit to run automated feature tests for API responsiveness, role validation, and spatial calculation accuracy. Concurrently, User Acceptance Testing (UAT) was conducted directly with the forest police and KPH managers to evaluate the usability of the interface and ensure that the digital workflow effectively mitigated the targeted organizational and physical barriers identified in the preliminary field study.

CONCLUSIONS

The performance of forest security officers in the Aceh Region V Forest Management Unit is constrained by three interrelated factors. Individual constraints concern technical ability, field skills, communication, and terrain mastery. Psychological constraints relate to motivation, perception, and attitudes in dealing with communities that depend on forests and regard them as ancestral land. Organizational constraints include insufficient personnel, limited budgets, inadequate infrastructure, and outdated monitoring equipment. Performance improvement therefore requires an integrated strategy: continuous competency development, stronger occupational support and work motivation, modern monitoring technology, adequate transportation and communication facilities, improved inter-agency coordination, and sustained community education. Community participation should be

institutionalized as a partner in early detection and forest protection rather than treated solely as an object of enforcement. This research contributes to the development of a decision support framework for forest patrol management by integrating GIS technologies with AI-driven predictive analytics. We have implemented a functional dashboard prototype that optimizes patrol routes and enables proactive incident classification, thereby addressing critical organizational and operational constraints in the Aceh Region V Forest Management Unit. While this study successfully demonstrates a viable technical solution, the system's performance is inherently tied to the quality and volume of available datasets. Future research should focus on scaling the system by incorporating larger, more diverse digital datasets to improve the robustness and generalizability of the AI models

REFERENCES

"As Aceh Reels from Severe Floods, NTU-Led Study in 2024 Traces Roots to Forest Loss." The Straits Times [Singapore], 5 Jan. 2026. The Straits Times, https://www.straitstimes.com/singapore/environment/as-aceh-reels-from-severe-floods-ntu-led-study-in-2024-traces-the-roots-to-forest-loss#:~:text=SINGAPORE%20%E2%80%93%20While%20land%20clearing%20for%20plantations,on%20previous%20floods%20in%20Indonesia's%20westernmost%20province.

Kelode, Chief Editor-Biplab Auddya, Editor-Dr Radha Narayan, Dr Pramod Kumar, Dr Nisha, Ms Revathy A. R, Smt Dipika Dnyaneshwar Jeughale, Dr Sandip R. Multidisciplinary Research Area in Arts, Science & Commerce (Volume-4). The Hill Publication, 2025.

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A Design Science Research Methodology for Information Systems Research. Journal of Management Information Systems, 24(3), 45–77.

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in Information Systems Research. MIS Quarterly, 28(1), 75–105.

Brooks, I. (2020). The United Nations Sustainable Development Goals in Systems Engineering: Eliciting sustainability requirements. https://doi.org/10.48550/arXiv.2006.10528

Educational Foundation for Nuclear Science. (1972). Bulletin of the Atomic Scientists. Educational Foundation for Nuclear Science, Inc.

Engström, E., Storey, M.-A., Runeson, P., Höst, M., & Baldassarre, M. (2020). How software engineering research aligns with design science: A review. Empirical Software Engineering, 25. https://doi.org/10.1007/s10664-020-09818-7

Hevner, A., R, A., March, S., T, S., Park, Park, J., … Sudha. (2004). Design Science in Information Systems Research. Management Information Systems Quarterly, 28, 75.

Loomis, J. J., de Araújo e Souza, F., Angel, M., & Fabbri, A. (2024). Technology-enhanced community forest management in tropical regions: A state of the art. Journal of Environmental Management, 350, 119651. https://doi.org/10.1016/j.jenvman.2023.119651

Mandala, A. S., Kisman, Z., Kanto, R. D. S., & Trisilo, R. B. (2025). The Effect Of Workload And Work Environment On Employee Performance With Job Satisfaction As A Mediator. Islamic Banking : Jurnal Pemikiran Dan Pengembangan Perbankan Syariah, 11(1), 171–182. https://doi.org/10.36908/isbank.v11i1.1570

Packalen, T., Marques, A., Rasinmäki, J., Rosset, C., Mounir, F., Rodriguez, L. C. E., & Nobre, S. R. (2013). Review. A brief overview of forest management decision support systems (FMDSS) listed in the FORSYS wiki. Forest Systems, 22(2), 263–269. https://doi.org/10.5424/fs/2013222-03192

Peffers, K., Tuunanen, T., Rothenberger, M., & Chatterjee, S. (2007). A design science research methodology for information systems research. Journal of Management Information Systems, 24, 45–77.

Szafarczyk, A., & Agbasi, O. (2025). Emerging trends in GIS and remote sensing technologies for environmental monitoring: Innovations, applications, and future directions. Geoinformatica Polonica, 24, 25. https://doi.org/10.4467/21995923GP.25.002.22857

Tanjung, F., Kusmanto, H., Isnaini, Adam, & Siregar, A. (2021). CITRONELLA GRASS PLANTATION AND THE MOUNT LEUSER NATIONAL PARK DEFORESTATION: AN EMERGING CASE IN THE GAYO LUES REGENCY, ACEH -INDONESIA.

White, J. C., Coops, N. C., Wulder, M. A., Vastaranta, M., Hilker, T., & Tompalski, P. (2016). Remote Sensing Technologies for Enhancing Forest Inventories: A Review. Canadian Journal of Remote Sensing, 42(5), 619–641. https://doi.org/10.1080/07038992.2016.1207484