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Indonesian Forest and Land Fire Prevention Patrol System

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Abstract: (1) Background: The management of forest and land fires has become of concern to the Indonesian government, as demonstrated by the issuing of the Presidential Instruction of the Republic of Indonesia Number 11 of 2015, then replaced by Number 3 of 2020, concerning Forest and Land Fire Management. In 2002, the Ministry of Environment and Forestry (MoEF) established Manggala Agni, a forest fire management organization, at the central government level. This study aims to explain the development of the Indonesian Forest and Land Fire Prevention Patrol System. The system development was conducted by the Computer Science Department of IPB University, in collaboration with the Agency for Climate Change and Forest and Land Fire Management, as well as the Directorate of Forest and Land Fire Management, MoEF. (2) Methods: The system development adopted the steps in the prototyping method, namely communication, quick planning, rapid design modeling, and prototype construction, as well as dissemination, submission, and feedback. (3) Results: The web-based system for the real-time monitoring and analysis of the forest and land fire prevention patrol is integrated into a mobile application for recording field observations during patrol activities. The system testing was successfully conducted by involving the users. The test results show that all features in the system are working correctly and meet the user's requirements. The mobile application has saved 36.02% of the time for recording the patrol data and 40.32% for creating the patrol reports. In addition, using the web-based application has saved time in preparing the patrol reports by 56.48%.

Keywords: forest and land fires; information system; mobile application; prevention patrol; prototyping method

Citation: Sitanggang, I.S.; Syaufina, L.; Trisminingsih, R.; Ramdhany, D.; Nuradi, E.; Hidayat, M.F.A.; Rahmawan, H.; Wulandari; Ardiansyah, F.; Albar, I.; et al. Indonesian Forest and Land Fire Prevention Patrol System. *Fire* **2022**, *5*, 136. https://doi.org/10.3390/fire5050136

Academic Editor: Natasha Ribeiro

Received: 12 August 2022
Accepted: 7 September 2022
Published: 9 September 2022

1. Introduction

Forest and land fire is an event of forest and/or land burning, either naturally or by human actions, resulting in environmental damage that causes ecological, economic, socio-cultural, and political losses [1]. In 2015, the total area of forest and land fires in Indonesia reached 2,611,411.44 hectares; the area affected by forest fires in 2015 was the worst land and forest fires affected-area from 2013 to 2022 [2]. Forest fires cause smog and haze pollution, as well as increasing carbon emissions. Other adverse impacts include forest product degradation and deforestation, the loss of forest products and flood control functions, and the loss of biodiversity [3]. It is necessary to take appropriate field measures of environmental conditions to prevent and manage forest and land fires and to minimize their adverse impacts.

Forest and land fire prevention is an effective and efficient approach to reducing the fires' negative impacts. This approach has become a concern in many countries where fires

frequently occur, especially in the dry season, because fire prevention costs less than fire suppression, especially in large-scale fires. Fire-risk modeling is one of the activities in forest and land fire prevention and management in some countries, including China [4–11], Spain [12,13], Greece [14], Italy [15], South America [16], Siberia [17,18], Kenya [19], Vietnam [20], and South Korea [21]. Humans, flora, and fauna experience the environmental losses due to forest and land fires. The relationship between the influencing factors of the fire occurrence, including the vegetation, weather, and human activities, is studied by mapping the fire-risk areas. The environmental parameters, such as the temperature, precipitation, and humidity, are mostly analyzed in fire-risk modelling because fire incidence is highly influenced by the weather conditions [4–11,16,19]. In addition to the weather parameters, anthropogenic factors are essential in fire risk modeling because, in some countries, including Indonesia, fires are frequently caused by human activities, which is closely related to socio-economic aspects [6–8,11,16,18,19,21]. Forest and land fire prevention programs have been conducted in Southeast Asian countries, especially Malaysia and Brunei Darussalam. The Internet of Things (IoT)-based remote system was developed to real-time monitor peat swamp forest areas in Brunei Darussalam [22] and the Raja Musa Forest Reserve (RMFR), Selangor, Malaysia [23,24]. The systems record environmental parameters such as the soil and water temperature, soil moisture, water level, wind direction, and atmospheric humidity and pressure. These parameters are essential in creating an early warning of peat fires.

The management of forest and land fires has also become the Indonesian government's concern, as demonstrated by the issuance of the Presidential Instruction of the Republic of Indonesia Number 11 of 2015, which focuses on improving forest and land fire management, and was then replaced by Number 3 of 2020. The President has instructed the strengthening of cross-agency coordination (central and regional), increasing of community/stakeholder participation, and carrying out of law enforcement against the perpetrators involved in land and forest burning, either the individuals or legal entities [25]. In 2002, the Ministry of Environment and Forestry (MoEF) established Manggala Agni, a forest fire management organization at the central government level. Manggala Agni is a fire brigade team of technical operational personnel for forest and land fire management. One of the activities conducted by Manggala Agni is the integrated forest and land fire patrol, which is carried out with several other parties to prevent and manage forest fires [1]. The relevant parties involved in the integrated patrol are police officers, Indonesian National Armed Forces members, village officials, or volunteer groups from the Fire Care Community [1]. Furthermore, the implementation of field checks for information on hotspots and information on forest and land fires is regulated in the regulation of the Indonesian MoEF Number P.8/MENLHK/SETJEN/KUM.1/3/2018 [26].

This study aims to explain the development of the Indonesian Forest and Land Fire Prevention Patrol System. The system development was conducted by the Computer Science Department of IPB University, in collaboration with the Agency for Climate Change and Forest and Land Fire Management, as well as the Directorate of Forest and Land Fire Management, MoEF. The system has three main components: a mobile application for recording the field data, a spatial database of the field observations, and a web-based application for real-time monitoring and analysis of the patrol data. The patrol data contain the climate, topography, vegetation, and socio-economic factors essential for managing and preventing forest and land fires.

2. Forest and Land Fire Prevention in Indonesia

Early detection of forest and land fires in Indonesia is conducted through tools such as watchtowers or CCTV, heat sensors, devices for processing hotspot data, global positioning systems, drones, ultra-light trikes, and airplanes [1]. Hotspot occurrences are commonly used to characterize forest and land fires in Indonesia, although not all hotspots indicate fires in the field. The MoEF processes and distributes hotspot data and information for forest and land fire management. A hotspot is a location with a relatively higher temperature

than the surrounding area. A hotspot represents a pixel with a temperature value above a certain threshold, as the result of remote sensing, which can indicate forest and land fires [26]. SiPongi is a system developed by the MoEF to monitor forest and land fires in Indonesia (Figure 1), accessed at https://sipongi.menlhk.go.id/ (accessed on 9 April 2022). SiPongi can update hotspot data throughout Indonesia in real-time. The interval can be set to any specific period, for example, 12 h, 24 h, or 48 h.

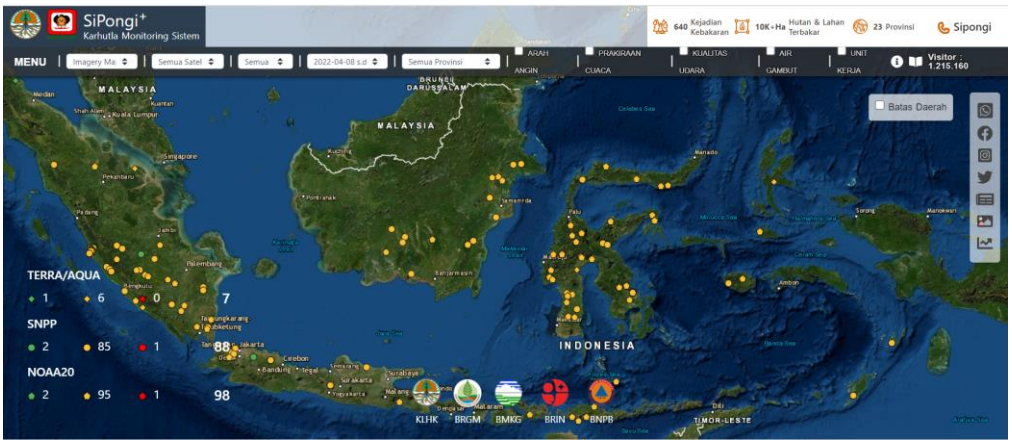

Figure 1. Hotspot distribution in Indonesia on 8–9 April 2022 with confidence levels high (red), medium (yellow), and low (green), reported by the Karhutla Monitoring System SiPongi (https://sipongi.menlhk.go.id/ (accessed on 9 April 2022)).

The hotspot distribution in the Indonesian region is presented, based on three types of hotspot satellites, namely Terra/Aqua, SNPP, and NOAA20. All confidence levels of the hotspots are considered to be displayed for the public as an early warning of forest and land fire occurrences. The hotspot confidence level of 80–100% is classified as high (red), 30–79% as medium (yellow), and ≤30% as low (green) [26].

The MoEF Indonesia has established several integrated patrol teams with members from Manggala Agni and other related parties to prevent forest and land fires, under the regulation of MoEF No. P.32 of 2016. The day-to-day duties of the integrated patrol team include:

1. Monitoring the area (water sources, peat depth, water level, fuel accumulation, weather, community activities in at-risk forest areas, and land fires);
2. Socialization regarding integrated patrol activities and the importance of preventing forest and land fires, counseling and distributing brochures and leaflets about the forest and land fire campaign;
3. Searching information and mapping problems related to forest and land fires;
4. Conducting a hotspot ground check if a hotspot is detected in the operational area;
5. Performing initial suppression when finding the initial fire and reporting on the implementation of tasks;
6. Recapitulating daily online and written reports.

The daily hotspots reported in SiPongi can be accessed by the forest and land fire patrol team through the mobile application. The integrated patrol teams perform a hotspot ground check daily to identify the fire spots. The team obtains the hotspot information from SiPongi and other sources such as CCTV, community reports, air patrol, and stakeholders.

A further analysis of hotspots is carried out by checking directly the hotspot locations to determine whether the data regarding the presence of land and forest fires are true. Integrated patrols prioritize the principle of early detection to minimize the negative impacts of forest and land fires. Ground check activities are conducted when hotspots appear, and there are direct reports from the local community. Through the ground checks, immediate fire suppression can be carried out if a fire is found, thereby preventing the

spread of the fire. The ground check locations follow GPS coordinates, adjusted to the appearance of hotspots from the remote sensing satellites.

3. Materials and Methods

3.1. Materials

The data used are field observation records collected during Sumatera's forest and land fire patrol activities. Sumatera's forest and land fire patrol is conducted in five provinces: North Sumatera, Riau, Riau Islands, Jambi, and South Sumatera. Each province has one or more local fire station(s) (Table 1) as the area for forest fire prevention patrols. The field data are retrieved from the forest and land fire patrol database.

Table 1. Local Fire Stations in Sumatera.

Province	Region	Local Fire Station
North Sumatera	North Sumatera and Aceh	SUM-I/Sibolangit
North Sumatera	North Sumatera	SUM-II/Pematangsiantar
North Sumatera	North Sumatera	SUM-III/Labuhanbatu Selatan
Riau	Riau and West Sumatera	SUM-IV/Pekanbaru
Riau	Riau	SUM-V/Dumai
Riau	Riau	SUM-VI/Siak
Riau	Riau and West Sumatera	SUM-VII/Rengat
Riau Islands	Riau Islands	SUM-VIII/Batam
Jambi	Jambi	SUM-IX/Kota Jambi
Jambi	Jambi	SUM-X/Muara Bulian
Jambi	Jambi	SUM-XI/Bukit Tempurung
Jambi	Jambi	SUM-XII/Muara Tebo
Jambi	Jambi	SUM-XIII/Sarolangun
South Sumatra	South Sumatera and Bangka Belitung	SUM-XIV/Banyuasin
South Sumatra	South Sumatera	SUM-XV/Musi Banyuasin
South Sumatra	South Sumatera, Bengkulu	SUM-XVI/Lahat
South Sumatra	South Sumatera, Bengkulu, and Lampung	SUM-XVII/OKI

3.2. Methods

The development of this information system uses the prototyping method [27], which consists of five stages. The five stages are communication, quick planning, rapid design modeling, prototype construction, and deployment, delivery, and feedback, which can be seen in Figure 2.

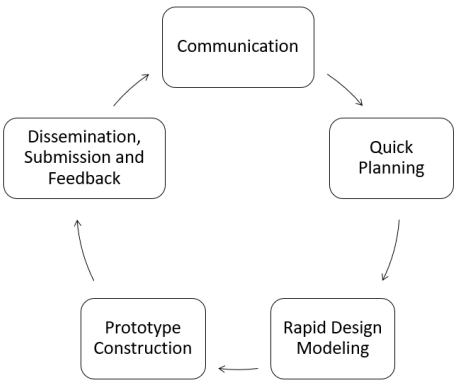

Figure 2. Prototyping method [27].

3.2.1. Communication

The system development begins with the communication step. We identified the hardware, software, and all the system requirements in this step. The focus group discussion held on 2 February 2019, with the Head of the Agency for Climate Change and

Forest and Land Fire Management Sumatera Region of the MoEF, discussed the flow of the forest and land fire prevention patrols. Manggala Agni and related parties conduct prevention patrol in fire-prone areas, based on an assignment from the Head of the Agency or head of the local fire stations. During the patrol, they report the field data, including general data about the patrol location, land patrol, weather data, fire risk conditions, and field observations. The field observations include the single leaf test, litter squeeze test, peat testing, water sources, vegetation, socialization, coordination, early suppression data during the patrol, and the hotspot ground check. The patrol data collected by patrol teams are sent to the administrator of local fire stations through the Whatsapp application. The administrators prepare the report in a spreadsheet format, and they send the reports to the Head of the Agency for Climate Change and Forest and Land Fire Management. The center administrator manages the patrol reports from all local fire stations in the Sumatera regions. The report of the Sumatera regions is sent to the Directorate of Forest and Land Fire Management, MoEF. This recording and reporting stage conducted manually has some issues to be addressed. Because the patrol data are saved in a text format on Whatsapp, the teams can lose the data when they have a problem with limited smartphone storage. Data loss may also occur when Whatsapp is restarting or having other issues. In addition, managing the reports from all the local fire stations needs more time, especially when the reports have more field documentation. Retrieving the information from the report is not easy, due to the unstructured format of the data repository. We collected the users' requirements for the back-end and front-end systems to overcome the problems in recording and managing the patrol data. The output of this stage is user stories representing their description of the system requirements.

3.2.2. Quick Planning

This step analyzes the user stories defined in the communication phase. As a result, we determined the modules of the mobile and web-based applications. The primary function of the mobile application is to record the patrol data and manage the patrol reports. Therefore, the modules in the mobile application are recording the patrol data, managing the images as field documentation, reporting the patrol data, editing the patrol reports, and reporting the live hotspots from Sipongi. The modules required in the web-based application are the patrol data monitoring, patrol data reporting, user management, assignment letter management, reporting on the hotspots from Sipongi, and the user's profile management. Each module is divided into views and services, so that the source codes of similar functions can be separated for easy system development.

3.2.3. Rapid Design Modeling

The next stage is modeling the information system based on the results of the quick planning. We conducted the modeling by creating user case diagrams and activity diagrams. The user case diagrams describe a list of activities that the actors in the system can carry out, while the activity diagrams show the activity steps of each task performed by the actors. The actor is a user who has access to the system. The mobile application's user is the patrol team, established by the Head of the Agency for Climate Change and Forest and Land Fire Management or the head of the local fire station. The users of the web-based application are the managerial levels in the local fire station, Agency for Climate Change and Forest and Land Fire Management, and Directorate of Forest and Land Fire Management, MoEF. We also performed the interface design of the application at this step. The interface design was distributed in xd format, created using Adobe XD with medium fidelity.

3.2.4. Prototype Construction

The interface design, user case diagrams, and activity diagrams of the mobile application were implemented using the framework Ionic 3. The framework Ionic 3 uses HTML and SCSS for the interface creation and Typescript for the mobile application's functionality. In this stage, we developed the prototype of the web-based application, using

the JavaScript programming language and a framework based on the React library. The back-end module was created using the Database Management System PostgreSQL with the extension PostGIS. The back-end module provides the data required by the modules of the mobile and web-based applications.

3.2.5. Dissemination, Submission, and Feedback

Before the system was delivered to the users, we conducted system testing to evaluate whether all functions were correctly implemented, based on the user requirements. We performed two types of testing: functional and usability. We adopt the black-box approach in the functional testing. The test produces feedback that is used to evaluate the system. If system functionality is not running correctly, the next iteration will be carried out by focusing on that functionality. If all functionalities have met the user requirements and no further system improvements are required, the system is released to the users. In addition to the black-box testing, we performed the usability testing of the mobile and web-based applications by involving the users. The usability testing of the mobile application was done using the concurrent think-aloud method. The performance metrics: the task success, error, and efficiency were used in the usability testing of the web-based application.

4. Results

4.1. General Design of the System

The Forest and Land Fire Prevention Patrol Information System manages the daily field observation data gathered by the patrol team during the forest and land fire prevention patrols. The system was developed by the Computer Science Department of IPB University, in collaboration with the Agency for Climate Change and Forest and Land Fire Management, as well as the Directorate of Forest and Land Fire Management, MoEF. The system has three main elements: a mobile application, a database management system, and a web-based application (Figure 3).

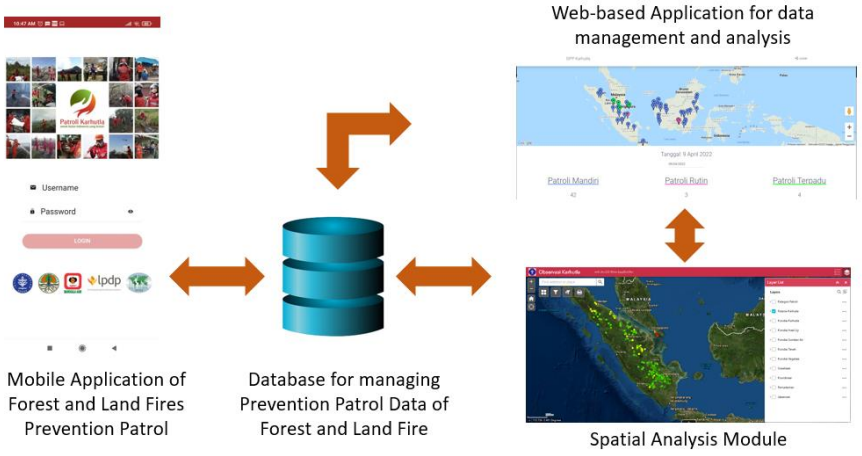

Figure 3. Forest and Land Fire Prevention Patrol Information System.

The forest and land fire patrol activities daily report the real conditions in the field. The daily report contains the patrol team identity, patrol locations, general condition of the burnt area, community activities, local weather conditions (temperature, precipitation, humidity), peat water level conditions, fire danger rating, and water source.

A mobile-based application is used to record the field conditions during the forest and land fire patrol activities. The application is integrated into the database management system and the web-based application. The data on forest and forest fire prevention activities consisting of 79 parameters are managed in the system. Table 2 summarizes those parameters. The system supports three types of forest and land fire prevention patrol: Independent, Routine, and Integrated [28].

Table 2. Patrol data.

Parameter	Value	Person in Charge/Custodian
Patrol Category	Independent, Routine, Integrated	Patrol team
Daily Activities	Morning Roll Call, Afternoon Roll Call, Briefing, Ground Check Hotspot, Social Communication, Coordination, Installing Information Media (leaflets/brochures, stickers, fire-prone area flags), Monitoring of Burned Areas, Early suppression, Socialization on Forest and Land Fires Prevention, Completing Administration, Compile other Patrol Reports	Patrol team
Patrol Member	Patrol Leader and Members present on patrol	Patrol team
Patrol Inventory	Stationery, Communication Tools, Vulnerability Flag, GPS, Engine Fire pump and accessories, Car, Motorcycles, Work Map, Fire flapper, Back pump, Measurement Stick/Measurement tape, Information media (leaflets/brochures, stickers, flags of fire-prone areas), Others	Patrol team
Satellite of hotspot	NOAA-20, SNPP, Terra/Aqua, Landsat 8	SiPongi developer, MoEF
Patrol Location	Coordinates, Village/Sub-district, District, Regency, Province	Google Maps API
Morning, Afternoon, and Evening Weather	Sunny, Partly Cloudy, Cloudy, Heavy Cloud, Foggy, Local Rain, Light Rain, Medium Rain, Thunderstorm	OpenWeatherMap API
Other weather conditions	Rainfall (mm), Temperature (°C), Humidity (%), Wind velocity (Km/h)	OpenWeatherMap API
Field Condition	There are forest and land fires, Former forest and land fires, Vulnerable to forest and land fires, No forest and land fires.	Patrol team
Forest and Land Fire Potential	Low, Medium, High, Extreme	Patrol team
Fine Fuel Moisture Code (FFMC), Fire Weather Index (FWI), Drought Code (DC)	Low, Medium, High, Extreme	Forest and Land Fire Warning System (https://spartan.bmkg.go.id/peta-interactive/ (accessed on 2 September 2022)) developed by Meteorology, Climatology, and Geophysical Agency
Community Activities	Available with frequent intensity, Exists with infrequent intensity, None	Patrol team
Accessibility	On foot, Ship, Boat, 2 Wheel, 4 Wheel, None	Patrol team
Field documentation	Photos	Patrol team

1. Independent: The supervision activities by Manggala Agni/civil servants/the Forest and Land Fire Management Brigade/Fire Care Community, and related parties to the work area to prevent, detect, and suppress forest fires early, using the facilities under local conditions to prevent and suppress the fire independently/functionally and periodically/a certain period, with a Letter of Assignment from the Head of the Technical Implementing Unit.

2. Routine: The monitoring activities by Manggala Agni and other parties in the context of preventing and suppressing forest and land fires independently/functionally and routinely/regularly as part of Manggala Agni's inherent duties in the context of preventing and suppressing forest and land fires early on orders from the heads of the local fire stations.
3. Integrated: The integrated patrol for the prevention of forest and land fires is the movement of a team consisting of, among others, Manggala Agni (firefighters of the MoEF), the army, police officers, representatives of the local government, and the fire care community of the work area to prevent, identify, and extinguish forest fires early, by using the facilities under local conditions, with a Letter of Assignment from the Director of Forest and Land Fire Management or the Head of the Technical Implementing Unit.

The forest and land fire prevention patrol data recorded through the mobile application are described in Tables 2–6. The patrol data consists of the patrol characteristics, including the patrol location, patrol category, patrol team, inventory, and accessibility (Table 2). The system records the patrol attributes so that the heads of the local fire stations know the personnel who are conduct a prevention patrol. The patrol teams bring the inventory appropriate to the activities performed during the patrol. The inventories include fire suppression equipment, information media for forest and land fire prevention campaigns, and a vehicle to access the patrol location. Accessibility is essential for other teams, mainly when fires occur in the patrol locations. In addition to the patrol characteristics, the mobile application records the weather conditions and fire danger ratings for early warning of forest and land fires.

Table 3. Test results and observation.

Parameter	Value
Single leaf test	Low, Medium, High, Extreme
Litter squeeze test	West, Humid, Dry
Peat test	Raw, Mature
Water sources	Lake, Dam, Irrigation, Canal, Pool, Ditch/Trench, Swamp, Socket, Well, Boreholes, River, No water source
Other characteristics of water sources	Length (m), Width (m), Diameter (m), Depth (cm), Water Level (cm)
Vegetation	Acacia, Banta (*Leersia hexandra*), Bonding, Melaleuca (*Melaleuca leucadendron*), Weeds, Karamunting (*Rhodomyrtus tomentosa*), Rubber (*Hevea brasiliensis*), Fern, Horticulture Crops, Lepironia, Sago Palm, Oil Palm, Bushes, Grasses, Sempuk, Others.
Category of Vegetation Condition (Water Content)	Wet, Humid, Dry
Land area (ha)	
Type of soil	Peat, Minerals, Swamp, Peaty soil
Other soil characteristics	Peat depth (m), Land slope (degrees)
Soil Condition	There is a forest fire, Former forest and land fires, Prone to forest and forest fires, No forest fires.
Change of former burned area	Industry, Field, Plantation, Mining, Agriculture, Settlement Shrubs, Other
Burnt area (ha)	
Field documentation	Photos

Table 4. Socialization and coordination data.

Parameter	Parameter Value
Local Community Activities	Hunting, Trading, Gardening, Farming, Fishing, Other
The profession of the majority of people at the patrol location	Laborer, Private Sector Team Member, Fisherman, Trader, Planters, Student, Farmer, Breeder, Civil Servant, Entrepreneur, Unemployed, Other
Village Potential	Industry, Trading, Fishery, Plantation, Mining, Agriculture, Housing Area, Other
Socialization Media	Leaflet/Booklet, Notice, Digital Media, Display, Placard, Poster, Flyer, Banner, Other
Type of Agency/parties for coordination activities	Community Group, Local Government (District/District), Village/Sub-district elements (RT/RW/Head of Village/Environment), Company, Police, School, Army, Traditional Figures, Religious leaders, Public figure, Other
Field documentation	Photos

Table 5. Early suppression data during a patrol.

Parameter	Value
Type of fire	Ground fire, Surface fire, Crown fire
Land status	Other Land use Areas, Protected Forest, Business Use Rights/Plantation, Indigenous Forest, Village Forest, Production forest, Permanent Production Forest, Convertible Production Forest, Conservation Forest, Community land, Other
Landowner	Public, Country, Permit holder, Company, Unknown
Causes of Forest and Land Fires	Negligence, Unintentional, On purpose, Unknown
Fuel types	Acacia, Banta (*Leersia hexandra*), Bonding, Melaleuca (*Melaleuca leucadendron*), Weeds, Karamunting (*Rhodomyrtus tomentosa*), Rubber (*Hevea brasiliensis*), Fern Horticulture Crops, Lepironia, Sago Palm, Oil Palm, Bushes, Grasses, Sempuk, Others
Burned area (ha)	A numerical value is an estimate or secondary data from the community
Suppressed area (ha)	A numerical value is an estimate or secondary data from the community
Suppression Results	Suppressed, Not suppressed yet
Field documentation	Photos

During the patrol, the team conducts several tests, such as a single leaf, litter squeeze, and peat, indicating the fire potential (Table 3). Another activity is field observation to record the vegetation condition, water source, and soil condition. The vegetation and soil conditions will affect the fire potential by altering the properties of the fuel. The water source data are needed to estimate the water reserve in case a fire occurs in the patrol location and surrounding area.

The MoEF involves stakeholders in forest and land fire prevention. As one of the stakeholders, the local community has a vital role in keeping their villages safe from fires. In addition to recording the physical properties of a fire-prone area, the patrol teams perform forest and land fire prevention campaigns to improve the local community awareness and participation in forest and land fire prevention (Table 4).

Table 6. Hotspot ground check during patrol activities.

Parameter	Value
Date and time of observation	Latitude, Longitude, Village, Subdistrict, Regency, Province
Hotspot Date	dd-mm-yyyy
Hotspot Location	Latitude and Longitude
Hotspot Confidence	Low, Medium, High
Hotspot/Fire spot Information Source	Firefighter station's CCTV, Community Report, Satellite Watch, Air Patrol Stakeholders
Satellite	Landsat 8, NOAA-20, SNPP, Terra/Aqua
False Hotspot	No, Yes
False Hotspot Description	Zinc Roof, Water Body, Chimney, Open Land, Nickel Mine Waste, Oily Drilling Well, Pile of Coal, Combustion Furnace, Others
Estimated fire area (ha)	Numerical value
Field documentation	Photos

Patrol is a surveillance activity carried out by Manggala Agni and all parties to prevent and suppress forest and land fires. Early fire suppression can contribute to reducing the negative effect of fires. The data recorded during the early fire suppression include the type of fire, causes of forest and land fires, fuel types, landowner, and suppressed area (ha) (Table 5).

Manggala Agni and other stakeholders conduct ground checks in areas that are monitored for hotspots. During the field check of a hotspot, the patrol team identifies whether a hotspot is a fire spot or a false hotspot. The other parameters during the hotspot ground check are the location, date, and confidence of hotspots, hotspot/fire spot information source, the satellite that detects the hotspot, false hotspot description, and estimated fire area (Table 6).

4.2. Mobile Application

A mobile-based application facilitates the patrol team's recording and reporting of the field data. We adopted the prototyping method [27] during the system development. Due to the dynamic changes in the user requirements, this study performed the prototyping in four iterations. The main tasks in each iteration are as follows.

- Iteration 1: developing the mobile application for recording 68 patrol parameters;
- Iteration 2: retrieving the weather data and patrol locations using the Application Programming Interface (API), generating a report in the PDF format;
- Iteration 3: updating the parameters based on the characteristics of the patrol area in Kalimantan, handling the data-recording in the locations with low or no internet connection;
- Iteration 4: developing the hotspot ground check module.

Currently, the mobile application records and manages 79 parameters of prevention patrol, including general data, land data, and observation data (Tables 2–6). Patrol locations, including coordinates, villages, sub-districts, districts, and provinces, are automatically retrieved using the Google Maps API. The application obtains the weather data (rainfall, temperature, humidity, wind speed) from the OpenWeatherMap API. The patrol teams can update the coordinates of the patrol locations and weather data in the field to reflect the actual conditions.

The patrol teams should be registered in the web-based application. The patrol teams who will conduct the prevention patrol activities are stated in the assignment letter from

the Head of the Agency for Climate Change and Forest and Land Fire Management, MoEF. Figure 4 shows the interfaces of the mobile application. The users can generate the reports of patrol activities in PDF format through the mobile application (Figure 5).

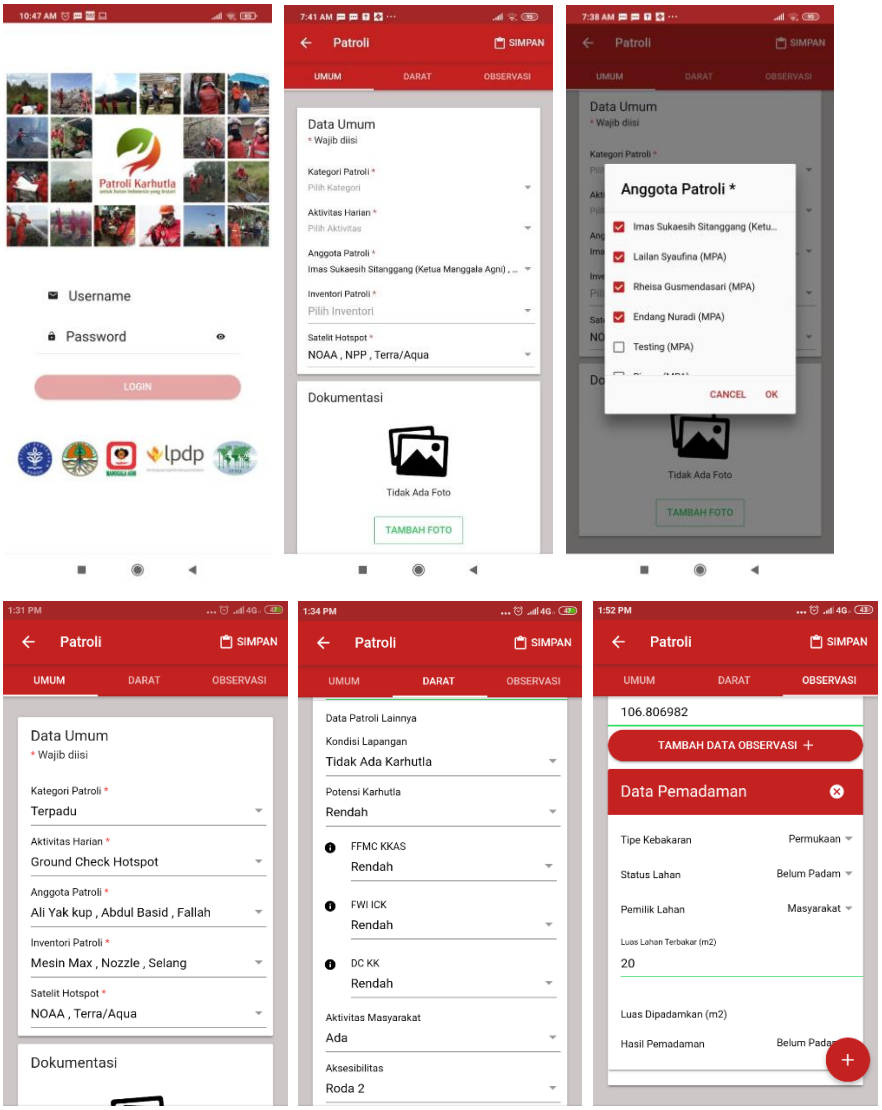

Figure 4. The interface of the mobile application.

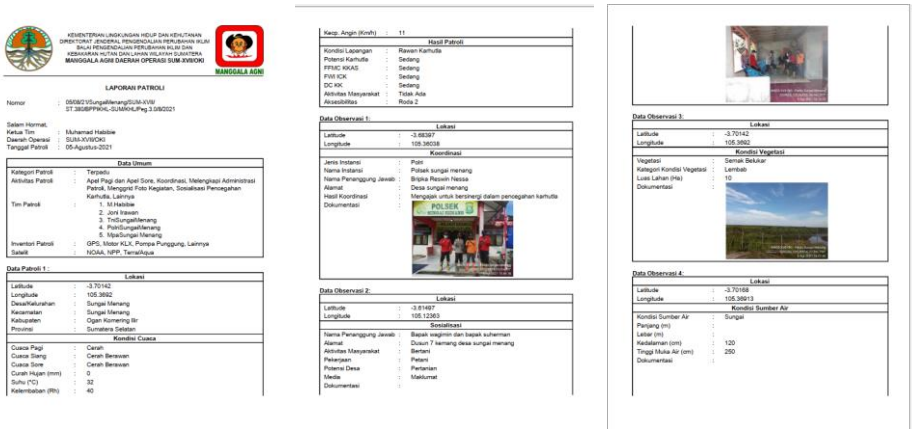

Figure 5. Forest and land fire prevention patrol report.

One of the observation modules available in the mobile application is the hotspot ground check. The patrol teams use this module to record the field data of hotspot locations (Table 6). To support the patrol teams in conducting the hotspot ground check, we implemented the live hotspots in the mobile application. The hotspot data are collected in real-time from Sipongi MoEF (https://sipongi.menlhk.go.id/ (accessed on 2 September 2022)). Figure 6 illustrates some interfaces of the hotspot ground check module. There are three hotspot confidence levels: low (<30%) marked as green, medium (30–79%) marked as yellow, and high (≥80%) marked as red. The hotspot confidence level categories refer to the Regulation of the Minister of Environment and Forestry [26]. We integrated the module with the Google Map to provide a path to the hotspot location.

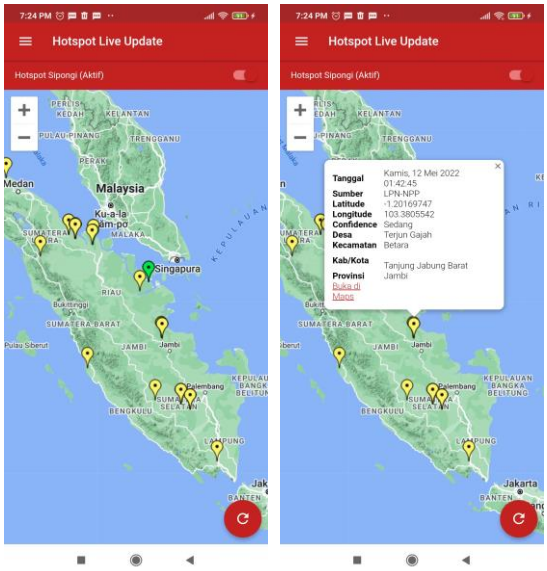

Figure 6. Live update hotspot from Sipongi.

The fire-prone areas in Sumatera are mostly located in remote areas. Therefore, the mobile application is designed to work in locations with and without an internet connection. When the application is used in a location with low or without internet connection, the recorded data are temporarily saved in the smartphone. The data will be automatically sent to the server once the patrol team reaches an area with an internet connection.

We conducted two types of testing on the mobile application: functional testing and usability testing. This study conducted functional testing by adopting the black-box approach [29]. We defined the testing scenarios based on the user's requirements of the application. The developers tested all scenarios, and the final iteration results show that all mobile application functions are working correctly. The functional testing also involved the users, namely the patrol teams, to evaluate whether all modules are working correctly or not. We performed the testing in several stages in several areas on Sumatera Island. Figure 7 documents the functional testing.

In addition to the functional testing, we performed the usability testing of the mobile applications using the concurrent think-aloud (CTA) method. CTA allows respondents to express their opinion while completing the tasks [30]. We defined ten tasks to be tested by four respondents. The average task success of all the scenarios reaches 83.9%, much higher than the threshold of 75%. This result shows that the success rate of the respondents in using the mobile application is quite good. We proposed some recommendations based on the usability testing and adopted those recommendations in the system development to produce the final version of the mobile application.

South Sumatera (10 December 2019)

Jambi (13 October 2021)

Jambi (14 October 2021)

Riau (9 November 2021)

Jambi (13 May 2022)

Figure 7. Mobile application testing documentation.

4.3. Web-Based Application

The Web-Based Forest and Land Fire Patrol Prevention Information System manages the data on patrols to prevent forest and land fires. The system can also be used as a decision support system for preventing forest and land fires in Indonesia. Currently, the web-based application is available at http://karhutla.apps.cs.ipb.ac.id/ (accessed on 8 August 2022). The main features of the system are:

- Real-time monitoring of the patrol activities;
- Patrol activity data management, including deleting, updating, and reporting;
- User management of mobile and web-based application;
- Spatial data analysis of historical patrol data;
- Visualizing the live hotspots from SiPongi.

Figure 8 shows forest and land fire patrol locations that we can access on the web-based system. Patrol activities on July 28, 2022 were conducted in some fire-prone areas on three islands: Sumatera, Kalimantan, and Sulawesi (Figure 8). There were 21 independent patrols (blue pins), five routine patrols (red pins), and 45 integrated patrols (green pins) on July 28, 2022 (Figure 8). Public users can obtain the patrol locations, local fire stations, and the head of the patrol team. Detailed reports are available for the registered users.

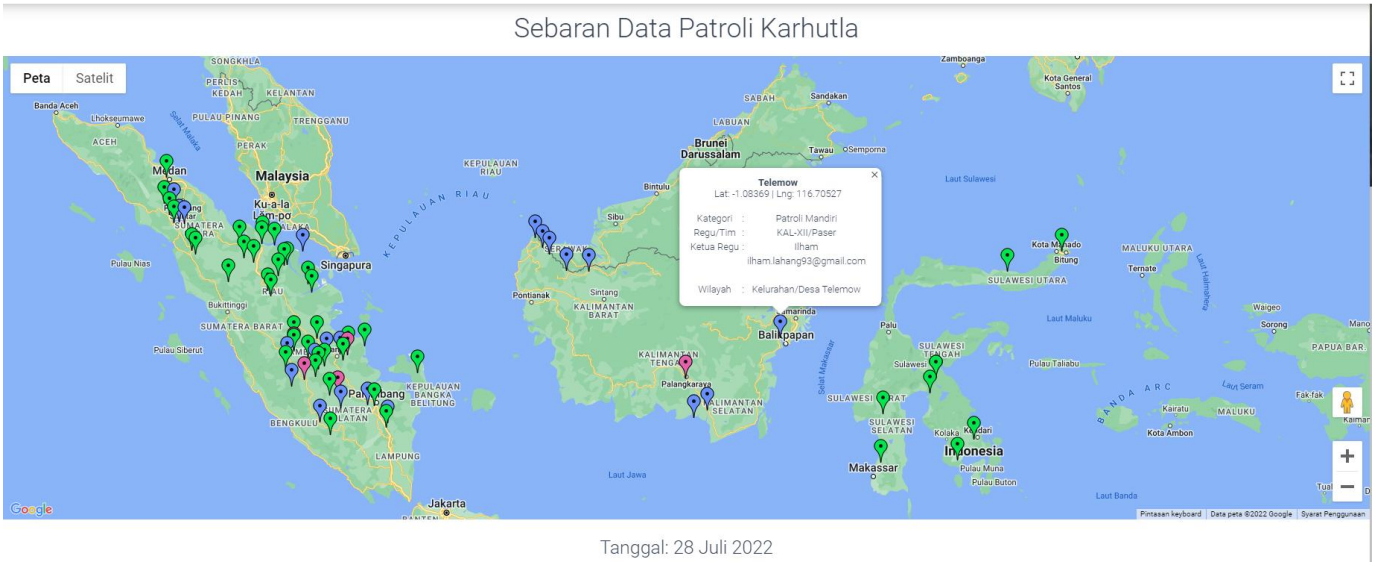

Figure 8. Web-Based Forest and Land Fire Patrol Prevention Information System.

To manage the patrol data efficiently, we define the different roles of each user of the web-based system. These are the groups of users:

- The administrator of the Directorate of Forest and Land Fire Management, MoEF;
- The administrator and Head of the Agency for Climate Change and Forest and Land Fire Management;

1. The administrator and Head of Regional Coordination;

- The administrator and head of the local fire stations;
- Non-login users.

The administrator of the Directorate of Forest and Land Fire Management, MoEF, can access the data of all the regions in Indonesia. The administrator and the Head of the Agency for Climate Change and Forest and Land Fire Management manage the data at the island level. The administrator and the Head of Regional Coordination can retrieve the data at the province levels. The administrator and the head of the local fire stations' access are limited to the data at the level of the local fire stations (Table 1). Table 7 provides the users' access levels to the system's features based on their roles.

At the end of the system development stage, we performed two types of testing: functional and usability, of the web-based application. This study conducted a black-box approach to test the system's functions. We determine the test scenarios based on the features and users' requirements. The results show that the testing output of all the scenarios meets the expected results. Therefore, we conclude that all features in the system are working correctly.

In the usability testing, we involved four administrators of a local fire station in South Sumatera as the respondents. The testing was held at the Agency for Climate Change and Forest and Land Fire Management, Sumatera Region on March 28, 2022. Figure 9 shows the testing documentation. There are 12 scenarios to be tested by the respondents. We formulated those scenarios based on the workflow of the patrol activities that are managed by the system. The scenarios include *report management*, *assignment letter management*, and *data analysis*.

Table 7. Role management of the system.

User Role	Home	Patrol	Report		User Management				Hots-Pot	Data Analysis	About	FAQ	User Profile
			Assignment Letter	Date Range	User's Data	Role	Assignment	Patrol Area					
Administrator of Directorate of Forest and Land Fire Management	V	V	V	V	V	V	V	V	V	V	V	V	V
Administrator of Agency for Climate Change and Forest and Land Fire Management	V	V	V	V	V	V	V	V	V	V	V	V	V
Head of Agency for Climate Change and Forest and Land Fire Management	V	V	V	V	X	X	V	V	V	V	V	V	V
Administrator of Regional Coordination	V	V	V	V	X	X	V	V	V	V	V	V	V
Head of Regional Coordination	V	V	V	V	X	X	V	V	V	V	V	V	V
Administrator of Local Fire Stations	V	V	V	V	X	X	V	V	V	V	V	V	V
Head of Local Fire Stations	V	V	V	V	X	X	V	V	V	V	V	V	V
Non-login user	V	X	X	X	X	X	X	X	X	X	X	X	X

Note: V indicates has access, X indicates no access.

Figure 9. Usability testing documentation.

The usability testing measured three performance metrics: the task success, error, and efficiency. The task success measurement measures how effective the user is in completing the given task [31]. This study uses a binary success (success and fail) model to measure task success. An error is an action that can prevent a user from completing a task efficiently. The objective of error measurement is to understand a series of actions that allow task failure to occur. We use the binary value of error measurement in which 0 indicates no error and 1 indicates an error. We count the errors when the respondent completes a task in the error measurement. We measure the efficiency by counting the number of actions and steps the respondents took to complete each task, such as the number of clicks. The more activities the user performs, the more effort is involved in the task. This study calculates efficiency measurement using lostness measures. The perfect lostness value is 0 [31]. The main problem with the usability of hypertext-based systems is that the user becomes lost during their use of the system [32]. The results of the usability testing of the web-based application are provided in Table 8. The web-based application has good usability in terms of the task success rate, reaching 89.58%. On average, there is one scenario that the respondents do not complete. All respondents experience at least one error in completing the 12 scenarios. The scenarios with the high errors are the *report management* in a specific period and the *spatial data analysis*, filtered by the date. A lostness value of 0.02 indicates that the respondents have a good understanding of the system's features.

Table 8. The results of web-based system usability testing.

Respondent	Task Success Rate (%)	Error	Lostness
Respondent 1	91.67	0.42	0
Respondent 2	91.67	0.67	0
Respondent 3	91.67	1	0.06
Respondent 4	83.33	1	0.02
Average	89.58	0.77	0.02

The Forest and Land Fire Prevention Patrol Information System has been regulated in the Regulation of the Director General of Climate Change Management of the Ministry of Environment and Forestry, No. P.10/PPI/SET/KUM.1/12/2020, dated 14 December 2020, concerning the procedures for using the Forest and Land Fires Prevention Patrol Information System. Now, the system is used by the patrol teams and managerial levels in the Sumatera, Kalimantan, and Sulawesi regions. Currently, we are initiating the utilization of the system to support forest and land fire prevention patrols in Java, Nusa Tenggara, Bali, Maluku, and Papua.

4.4. Spatial Data Analysis

The daily recording of the patrol data produces a large amount of data that can be used to support the decision-making regarding forest and land fire management in Indonesia. To help the users extract information from the database, we developed a module of spatial data analysis in the web-based system. The development steps in the spatial data analysis module are discussed in the previous study [33]. The data analysis module development utilized ArcGIS Online for visualizing and exploring the historical patrol data. Figure 10 shows the locations of the forest and land fire prevention patrols in 2020–2022 that can be accessed in the spatial data analysis module.

Figure 10. Forest and land fire prevention patrol locations in Indonesia in 2020–2022.

In addition to the patrol locations, the users can retrieve the layers of patrol data. The layers include the forest and land fire condition, potency of forest and land fire, single leaf test, squeeze litter test, water source, vegetation types, vegetation condition, soil type, community activities, potency of village, stakeholders, early suppression during patrol activity, and field observation location.

The spatial analysis using the distance operation available in the module can help users estimate the distance between the prone fire area to a water source (Figure 11). The

water source location is essential in the patrol activity, primarily where the fire occurred. The layer of water source contains the sites of various water sources and their characteristics as reported by the patrol teams during their patrol activities. In addition, we provide the layer of coastlines, reservoirs, lakes, and rivers collected from the Indonesia Geospatial Information Agency.

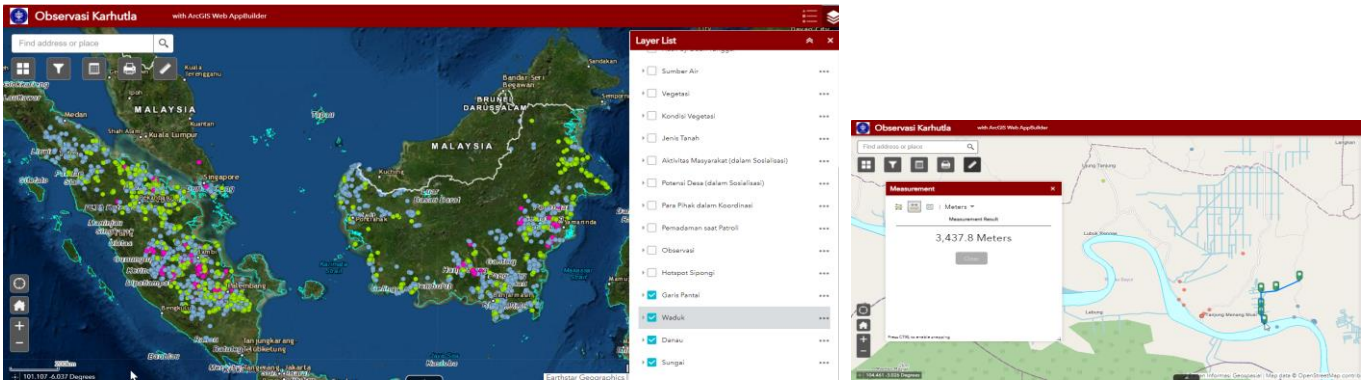

Figure 11. Distance measurement of patrol locations to a water body.

5. Discussion

Prevention patrol is one of Indonesia's priorities in forest and land fire management. The sStakeholders must collaborate to solve Indonesia's forest and land fire problems. In addition to solid cooperation between the related institutions, a large fire-prone area in Indonesia encourages the need for technology implementation to monitor the fire-prone areas so that early warning systems can be conducted more efficiently. The Forest and Land Fire Prevention Patrol Information System is an information technology product developed in a collaboration between IPB University, as the higher education institution, and the Indonesian government, namely the Ministry of Environment and Forestry. The system development was initiated in 2019 in the Sumatera regions, in partnership with Climate Change and Forest and Land Fire Management, Sumatera Region, MoEF. The mobile application is used to manage the influencing factors of fire occurrence, including the vegetation, weather, and human activities in the fire-prone areas. The vegetation and weather factors are essential to be analyzed because they have a significant relationship with the occurrence of fires, as reported in the previous studies [4–11,16,19]. Because Indonesian fires are frequently caused by human activities, socio-economic aspects are important in fire-risk modeling [6–8,11,13,16,18,19,21]. Therefore, the Forest and Land Fire Prevention Patrol Information System has significantly contributed to providing field data related to vegetation, weather, and human activities for forest and land fire risk modeling in Indonesia.

Currently, the system is used in Sumatera, Kalimantan, and Sulawesi to support forest and land fire prevention patrols. As many as 612 users utilized the system in the patrol activities in Sumatera in 2021. Figure 12 illustrates the number of users at the province level in Sumatera in 2021.

The patrol teams in South Sumatera dominated the use of the system, followed by Jambi and Riau. These three provinces have larger fire-prone areas compared to other provinces in Sumatera. Figure 13 shows that the system is frequently used in independent patrols (44.77%) and routine patrols (42.16%). Independent patrols are conducted by Manggala Agni (Forest and Land Fire Management Brigade) and related parties, with a Letter of Assignment from the Head of the Technical Implementing Unit. Manggala Agni and other parties conduct routine patrols as part of Manggala Agni's inherent duties in preventing and suppressing forest and land fires early, on orders from the Head of Operation Area. The system recorded 80 integrated patrols (13.07%) in Sumatera in 2021. Integrated patrols are performed by Manggala Agni (firefighters of MoEF) in collaboration with the army, police officers, local government representatives, and the fire care community,

with a Letter of Assignment from the Director of Forest and Land Fire Management or the Head of the Technical Implementing Unit.

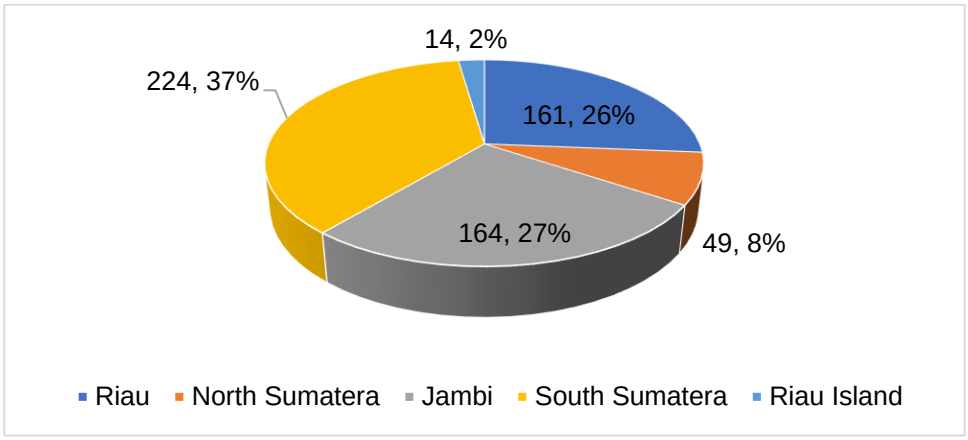

Figure 12. Number of users utilized the system in patrol activities in Sumatera in 2021.

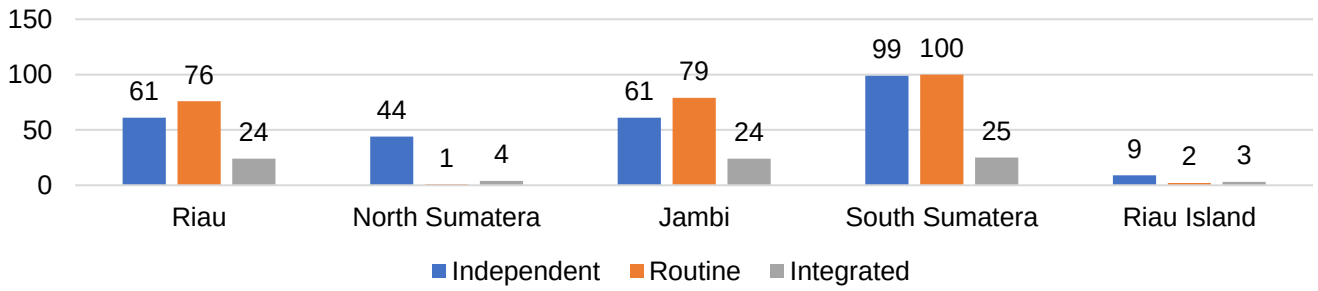

Figure 13. Types of patrol activities in Sumatera in 2021.

We evaluated the mobile application usage through an online survey conducted on 27 April–22 May 2022. As many as 106 patrol teams in the Sumatera and Kalimantan regions joined in the survey to assess the efficiency of the mobile application in supporting their duties during patrol activities. The survey results show that the time to record field data before and after using the mobile application is 30.34 min and 19.42 min, respectively. There is about a 36.02% time reduction in recording the field data by the patrol teams. We also evaluate the duration of time required for generating reports before and after using the mobile application. The time needed to create a patrol report reduces about 40.32%, from 45.04 min to 26.88 min, after implementing the mobile application. This assessment proves that utilizing the mobile application can help the teams to work faster in the forest and land fire prevention patrols.

In addition to the mobile application evaluation, we assessed the use of the web-based application. We surveyed, on 27 April–22 May 2022, 25 administrators of local fire stations in the Sumatera and Kalimantan regions. Report management is one feature in the system that the administrators of local fire stations frequently use. Before the system implementation, the patrol data were reported from the patrol team to the administrators of local fire stations through text messages using Whatsapp. Then, the administrators prepared reports in a spreadsheet format from the data delivered by Whatsapp. The administrators required about 31.46 min to make a report for a patrol activity. After applying the web-based application, the duration of the report preparation time reduced to 13.69 min. Therefore, the system has successfully supported the administrators in patrol report management time of 56.48% faster than the manual system. The respondents also expressed their opinions using the web-based application during the survey. Most of them stated that the application is easy to use, provides better data management and reports, makes report generation faster, as well as saves time and energy.

Further development of the Forest and Land Fire Prevention Patrol Information System should address some challenges. Large fire-prone areas in Indonesia with different characteristics lead to dynamic user requirement changes. The database and system architecture should be designed to handle the new users' requirements when the system is used in new areas. In addition, the fast growth of programming tools creates issues in updating the system. The next development of the system should adopt the recent software; therefore, the system can run more efficiently and be easy to update. In terms of user capability, the patrol teams' computer literacy differs. During the system development, we conducted online and offline mobile and web-based application workshops from June 2021 to 31 January 2022. The participants were patrol teams and the administrators of local fire stations in Sumatera, Kalimantan, Sulawesi, Java, Bali, Nusa Tenggara, Maluku, and Papua. Capacity building of the users should be continuously performed so that the patrol data they record and manage are valid and consistent. Another challenge in further system development is non-functional system evaluation. Because the field data are recorded daily, the volume of data stored in the database is increasing. The database size is growing significantly, especially when more images are captured and stored in the database. Non-functional testing, including load and scalability testing, is required to assess the system's performance in handling big data. Load testing evaluates the system's stability with a certain number of users simultaneously, without significantly reducing the system's performance. Scalability testing is a test of changes in the maximum load given to the application without violating the predetermined objectives.

6. Conclusions

In the era of Industrial Revolution 4.0, information technology has the potential to be adopted to support the Indonesian government's agenda in forest and land fire management. Large fire-prone areas in Indonesia need an information system that can efficiently manage big forest and land fire data. The Forest and Land Fire Prevention Patrol Information System was developed to support the government program in reducing forest and land fire occurrences in Indonesia. The system has three main components: the mobile application, database management system, and the web-based application that manages the patrol data in fire-prone areas. The system is now used by the patrol teams and managerial levels in local fire stations and the Agency for Climate Change and Forest and Land Fire Management, MoEF in, Sumatera, Kalimantan, and Sulawesi. The system's implementation has allowed the users to record and report real-time patrol data faster than in the previous design. We believe the system will contribute significantly to preventing forest and land fires in Indonesia. Further study could focus on developing a forest and land fire prediction model, based on the patrol data managed by the system.

7. Patents

- Copyright from the Director General of Intellectual Property, Ministry of Law and Human Rights Indonesia for the updated version of Forest and Land Fire Prevention Patrol Mobile Application Number EC00202258662.
- Copyright from the Director General of Intellectual Property, Ministry of Law and Human Rights Indonesia for the Forest and Land Fire Prevention Patrol Information System (SIPP Karhutla) Number EC00202259164.

Author Contributions: Conceptualization, I.S.S., L.S., I.A. and F.K.; methodology, I.S.S., R.T., H.R., F.A. and W.; software, D.R., E.N. and M.F.A.H.; validation, I.S.S., L.S. and F.K.; formal analysis, I.S.S., L.S., I.A. and F.K.; investigation, F.K.; resources, I.A. and F.K.; data curation, I.S.S., D.R. and F.K.; writing—original draft preparation, I.S.S. and L.S.; writing—review and editing, I.S.S. and I.A.; visualization, I.S.S.; supervision, I.S.S. and L.S.; project administration, W. and R.T.; funding acquisition, I.S.S., L.S., I.A. and F.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Innovative-Productive Research Program (RISPRO) of the Indonesian Endowment Fund for Education (LPDP), Ministry of Finance, Indonesia, grant number KEP-51/LPDP/2019 and the APC was funded by RISPRO-LPDP. This research was also funded by the International Tropical Timber Organization (ITTO), grant numbers 004/14/ITTO/PP-A/56-340-1/V/2021 and 1949/IT3.F7/HK.07.00/2021.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The authors would like to thank the Agency for Climate Change and Forest and Land Fire Management, and the Directorate of Forest and Land Fire Management, Ministry of Environment and Forestry, Indonesia, for sharing their knowledge, data, and facilities during the system development.

Conflicts of Interest: The authors declare no conflict of interest.

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