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Crowdsourced hotspot validation and data visualisation for location-based haze mitigation

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ABSTRACT

Haze over Sumatera and Kalimantan has been a prolonged trans-boundary issue in South East Asia mainly due to setting fire to drained peatland. At present, fire sources (i.e. hotspots) are located based on satellite data. Sensors such as MODIS and AVHRR detect extremes in average temperatures of an area. The hotspots have low spatial resolution and large spatial footprints, thus making it harder to detect fires. This research proposed a ground-based spatial validation of satellite data based on crowdsourcing in order to obtain more accurate estimates of the location and severity of the fire. We developed an Android application for reporting and validating fires in peatlands. Crowd data collected were integrated with satellite hotspot data by the dashboard system as a monitoring platform for government agencies. The 110,888 hectares of Padang Island, in Riau Province, were chosen as the study area given its vulnerability to peatland fire and imminent danger of subsidence as the collateral effect of draining peatlands. Residents of Padang Island tested the use-case scenario of the app to assess its applicability. The study showed the potential use of mobile apps for local communities to help the government validate hotspots for haze mitigation.

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Crowdsourcing; peat fires; hotspot; fire haze mitigation; visualisation

1. Introduction

Haze has been a trans-boundary issue for South East Asia for some time now. Most recently, in 2015, in Indonesia, 2.4 million hectares (ha) of forests, including peatland, were burnt, causing economic losses of USD 16.1 billion (Adriani et al. 2016). This estimate does not fully capture the health impact of the haze, although two children reportedly died (Ali 2015), or the loss of ecosystem services. Neither does it incorporate regional impacts caused by haze-related travel suspensions. The event also necessitated huge mobilisation as thousands fled their homes (Slezak 2015).

Forest fires and haze over Sumatera have been an acute risk owing to fires originating in drained peatland (Cattau et al. 2016). This is a frequent

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occurrence in dry periods; the level of severity varies depending on local weather conditions. Global climate extremes like El Niño events have worsened the situation (Bedia et al. 2015; Y. Liu, Stanturf, and Goodrick 2010; Miettinen, Shi, and Liew 2017). Peat fires are among the main sources of greenhouse emission and cause major economic losses (Adriani et al. 2016; Purnomo et al. 2017). Peat forest conversion to agricultural land by utilising drainage canals increases the risk of fires and thus must be reversed. Sumatera, including the area of study in Pulau Padang, has experienced massive ecosystem change from a 'frequently inundated and moist-ecosystem' into a human-made 'drained-ecosystem' (Susanti et al. 2018). Peat fires become everyone's problem with trans-boundary hazes causing diplomatic tensions (Afrida and Jong 2015; Desker 2015; McCafferty and Sater 2015).

In response to forest fires and to restore degraded peatland, the Indonesian government strengthened its peatland governance by setting up an agency to coordinate peatland restoration and issuing a new policy on peatland (Ompusunggu 2017; Witoelar 2016). However, the issue of peatland fires remains unresolved. The government relies heavily on hotspot satellite data to monitor and respond to peatland fires. Several parameters are used to identify these fires. They include cloud and water area masking, daytime/night-time acquisition and radiance of pixel (Giglio, Schroeder, and Justice 2016). It has been shown (Csiszar, Morisette, and Giglio 2006) that information from MODIS (Moderate Resolution Imaging Spectroradiometer) fire products need further validation, due to the low pixel resolution, geolocation accuracy (about 1 km) and other factors such as heavy smoke which obstructed the fire. Hantson et al. (2013) showed that although the MODIS fire product with high confidence (>80%) had a high accuracy for detecting burned areas, the relationship between hotspot with the real fires still depended on the type of land cover and slope values. These factors are especially important in cases of peat wildfires which could spread within hours and consist of a surface peat fire and deep peat fire (Usup et al. 2004). To avoid a false alarm and sending firefighters to the wrong location, in-situ validation of the satellite hotspot data is needed (Csiszar, Morisette, and Giglio 2006).

Local reports through on-site validation could strengthen the reliability of information systems that rely on weather conditions and hotspot information. Active data supply from local populations, through mobile devices, will help mitigate and prevent fires like the one in 2015 or even worse. As shown in (Giglio et al. 2003; Hantson et al. 2013), hotspot needs validation. As also voiced occasionally by the local government and firefighters that hotspot data only are not enough, field check and measurements are needed. Responsive validation can be gained with creating a canal for local communities to provide an active contribution to confirm hotspots by sending local reports. Such active contribution from the field would be useful to both the community and the government.

Mobile reporting through crowdsensing is expected to collect considerable data. In cases where other methods might be employed to collect data, only some individuals might volunteer information. A motivation for participating in crowdsensing is closely related to incentives. As crowdsourced geographic information require active contribution, incentives would be 'being part of a good cause, contributing to the greater good', which involve only a one-way information flow (e.g. burnt area mapping) or 'gaining something tangible from the site' that lead to higher participation, which then involve a two-way information flow (See et al. 2016). In the case of tropical peat fires, the local community expects to gain the second incentive that relates to protecting their village and their land from forest fire that would destroy their source of livelihood. As some studies point out (Adriani et al. 2016), the 'big fires' of 2015 cost Indonesia 16.1 billion USD that included losses to estate companies, smallholder farmers, and local farmers. Local communities affected by haze and fire were disturbed socially and economically, as local populations depend heavily on the affected land for their livelihood. Additionally, a hierarchy of leadership is still essential in remote areas where peat predominates. Community leaders and community firefighters dealt considerably with the fires and haze over their villages; thus, digital volunteerism was not the only level of community participation (Starbird 2011).

As hotspot information is commonly used to develop actions for fire control and management (Barbosa et al. 2010; Pratihast et al. 2016), validation of hotspot data must be strengthened (Atwood et al. 2016; Hantson et al. 2013; Tanpipat, Honda, and Nuchaiya 2009). To do so, we developed a hotspot validation and peatland degradation reporting system that supports peatland restoration programs. A visualisation and decision support tool has been an important research agenda in fire control (Lee and Amin 2016; Lopes and Machado 2014; Miettinen, Shi, and Liew 2017), including the use of crowdsourced data for field validation (Kadlec and Ames 2017; W. Liu et al. 2014; Sachdeva, McCaffrey, and Locke 2017). However, little has been done to support the use of hotspot validation using mobile apps for residents in remote areas, especially peatland areas. The research presented here is relevant to the social aspects of positioning, modelling and evaluation of LBS (Location-based Services) applications as addressed in the current LBS research challenge (Huang et al. 2018). While the progress on the positioning, modelling and evaluation of LBS applications is discussed in that issue, the introduction of a new LBS application to rural groups suffering from haze and peat fires discussed in this paper is expected to contribute on the design of LBS application for rural groups.

This paper presents an application that was motivated by the need to protect the rural groups in peatland area who were frequently disturbed when fire and haze surrounding their environment threatened their health and environment. Social networking among frequent app users could then be created by the government who might need to develop environment champions to fight fire and haze. The research aimed to answer the question: 'How can relevant information be communicated to LBS users optimally, to facilitate decision-making and activities related to land and environment?' (noted as space in the paper) (Huang et al. 2018). In order to tackle this research objective, citizen observations on fires and relevant causes of peatland degradation were delivered by local leaders and firefighters, through a mobile application capable in leveraging hotspot validation, on peatland areas that are difficult to access. A monitoring dashboard was designed on the server end to cast the field report and hotspot data to managers and decision makers in order to assess the field situation.

A peat fire reporting system needs to be adjusted to reflect the distinctive characteristics of peatlands. This research sought answers to two questions: (i) How useful is the citizen observatory system, social use of location-based reporting system, to validate hotspot data and to fight the immediate effects of peatland fires? Also, (ii) How can data reporting and visualisation be delivered to managers and decision makers?

2. Related works

2.1. Use of MODIS and AVHRR in fire reporting system

In cases of fires, the distinct features of peatlands necessitate a different treatment from typical forest areas (see (Page and Hooijer 2016)). The speed with which peat fires can spread means that near-real-time and accurate observation methods are needed to counter and prevent further damage. The current method for locating fires and fire sources (known as hotspots) utilises satellite data. MODIS and AVHRR (Advanced Very-High-Resolution Radiometer) are common satellite sensors used to detect hotspots based on extremes in average temperatures of an area. While useful for early detection, such methods are still prone to errors caused by natural occurrences, land surface temperature anomalies, and human activities. Thus, satellite-based hotspot information validation methods have been developed (Csiszar, Morisette, and Giglio 2006; Giglio, Schroeder, and Justice 2016; Tanpipat, Honda, and Nuchaiya 2009). As the hotspots have low resolution and cover a large area, fires become harder to detect and extinguish.

Since the country is prone to forest fires, the Indonesian government has implemented information systems such as SiPongi Fire Monitoring System (refer to http://sipongi.menlhk.go.id/) and BNPB Hotspot Monitoring System (refer to http://geospasial.bnpb.go.id/monitoring/hotspot/). These are official information systems managed by the government. Like in other developed systems, here too (Barbosa et al. 2010; Pratihast et al. 2016), the 'hotspots' are suspected incidents of fire identified using near-real-time satellite monitoring data. Each is shown with their hotspot confidence level, which indicates the certainty with which a particular hotspot can be considered a real fire or a false alarm. The higher the confidence level for a hotspot, the more likely that a particular hotspot indicates a real fire, and vice versa.

To obtain a more accurate estimate of the location and severity of a fire, for prevention and monitoring, hotspot data from satellite observations could be validated on the ground.

2.2. Existing crowdsourcing platform

Based on this line of reasoning, a near-real-time ground truth validation is needed to pinpoint the correct position and severity of peat wildfires accurately. A commonly used method is to utilise human dynamics data by involving communities to provide crowdsourced information for further analysis, including validation of satellite hotspot data. Some crowdsourcing platforms were established during previous disaster events and environmental monitoring.

Ushahidi (www.ushahidi.com) is a notable example of a crowdsourcing platform that enables disaster response managers and decision makers to harness near-real-time data regarding disasters such as the 2010 Haiti Earthquake (Morrow et al. 2011). Ushahidi gathers data from multiple sources, including user reports and tweets, to provide vital information to disaster response manager. Taiwan Scientific Earthquake Reporting System (TSER) is an example of Ushahidi-based crowdsourcing platform which dispatches targeted users (trained high school teachers and public volunteers) to collect data in epicentre area immediately after an earthquake occurred (Liang et al. 2017). Houston Harvey Rescue (Yuan and Liu 2018) is another example of crowdsourcing platform which, after combined with crowdsensor data, could be used to gather adequate data especially for rescuing citizens needed immediate response. Subsequent analysis of vulnerability and exposure data could then be used for Forensic Disaster Investigations (FDI) regarding Harvey Typhoon in Houston area.

Another notable example of crowdsourcing platform utilises satellite imagery as preliminary data for crowdsourcing. GeoCAN (Barrington et al. 2011) provides recently acquired high-resolution satellite imagery for crowd-based post-disaster damage assessment. GeoCAN was employed in the aftermath of Haiti Earthquake in 2010, as well as Christchurch in 2011, to enable volunteers to classify damaged buildings by comparing pre and post satellite imagery in the affected area. Accuracy of this method is shown to correspond with the level of expertise of the volunteers, resolution of satellite imagery and the level of damage (Foulser-Piggott et al. 2016). Similar method is employed in OpenIR initiatives by MIT Media Lab (Ducao 2013), where satellite imagery is preprocessed to provide estimation of inundated area for crowdsourcing validation based on Ushahidi. The platform also utilises OpenStreetMap (OSM) data to produce risk maps in Jakarta, Indonesia.

CROSS (Tsai et al. 2014) is another platform capable of collecting crowdsourced data. CROSS (Crowdsourcing Support System for Disaster Surveillance) employs registered participants to gather data using either system-driven or crowd-driven CDC (crowdsourcing data collection). The system-based data collection works by broadcasting request to users nearby the area to collect data, then provide a path to selected users to obtain the data. This way, the validity of the collected data could be ensured by limiting the data collection to users situated nearby the event, as well as to provide training to these users. Also, stochastic methods are employed to select these users' report to minimise potential false data. An Android App (i.e. 'I am here') is utilised by the user to collect data during a disaster event.

For social media data, e.g. Twitter, some authors develop platforms to obtain crowdsourced data. Tweak The Tweet (Starbird 2011) utilises Twitter to analyse social media information based on the data. A dashboard built by New South Wales Rural Fire Service (NSW RFS) also employs Twitter data and SVM Classifier to infer the occurrence of fire (Power, Robinson, and Colton 2015).

Based on Ushahidi, the common features of a crowdsourcing platform could be inferred as follows (Okolloh 2009): First, user-facing application (website or mobile app) for data collection and a dashboard for data managers. Secondly, utilising multiple platforms for reporting (such as SMS-based report, social media-based report and direct reporting through a mobile application or website). Thirdly, validations need to be performed by a data manager before the data can be used and posted on the map, to eliminate suspicious or false reports. Hazegazer, developed by Pulse Lab Jakarta (Lee and Amin 2016), exemplified the potential uses of social media for fire and haze control (Sachdeva, McCaffrey, and Locke 2017). As telecommunications platforms are still limited in many settlements surrounding peatlands, the communities need to have a system that can accommodate SMS-based reports.

According to a review by See et al. (2016) in characterising crowdsourced geographic information, the work presented here can be seen as a reporting system producing active georeferenced non-framework data (i.e. environmental monitoring) with passive non-georeferenced data (i.e. social media) used as the background. Kadlec and Ames (2017) also make use of active georeferenced non-framework data to fill cloud gaps in MODIS snow cover datasets. They estimate snow cover based on incoming user reports. Possibilities on the use of active georeferenced crowdsourced data have been showcased in real-time wildfire estimation and geo-web crisis management (Roche, Propeck-Zimmermann, and Mericskay 2013; Zhong et al. 2016). The crowd-sourced data from mobile sensors can also be used to support noise simulations (Hu et al. 2015). The discussion on the context and location for using active georeferenced crowdsourced data for haze mitigation is presented in the next section.

As described by (Poblet, García-Cuesta, and Casanovas 2014), some basic characteristics of crowdsourcing platforms could be categorised based on the users' role and level of data processing method. For the case of collecting peat wildfires incidents through crowdsourcing, we targeted to obtain semi-structured and structured data, since preliminary criterion have been established previously through satellite imagery (i.e. is the fire occurrence valid or not?). Thus, the Geocrowd app's users are either 'crowd as reporter' (local civilian) or 'crowd as a microtasker' (fire-aware community). The method applied in CROSS (Tsai et al. 2014) could be utilised to collect data where hotspot occurred in a certain area. The user should be able to validate satellite-based hotspot data (system-driven data collection) or independently report a fire occurrence in peatland area (crowd-driven data collection). Constrained by the availability of mobile network in a peatland area, the Geocrowd app is designed to gather as much data as possible in limited network area, while still being able to provide useful information during a critical event. Based on this rationale, the Geocrowd app and dashboard system is developed. Table 1 provides a comparison of Geocrowd with some other platforms as mentioned above.

Based on Table 1, it can be concluded that Geocrowd is tailored for reporting fire incidents in peatland area where limited network coverage is a common issue. Geocrowd leverage the ability to detect fire hotspot in near-real time by providing user validation to satellite-based reporting. This is similar to the approach implemented in GeoCAN (Barrington et al. 2011) and OpenIR (Ducao 2013) where satellite imagery is utilised to provide preliminary data for users. However, in both cases, these preliminary satellite imagery data does not affect the users in any way. In GeoCAN, high-resolution satellite imagery is used as a base map where volunteers could digitise and classify damaged buildings. The users could be situated outside of the affected area, or even abroad. This, as pointed out by Foulser-Piggot et al. (2016), could potentially lead to errors where users with a low level of expertise are involved. In OpenIR, infrared band from various medium-resolution satellites is used to provide visual cue to users to identify flood. However, no restrictions (e.g. location) applied to users regarding to their report. In Geocrowd, if a hotspot with high confidence (>80%) occurred, nearby users would be notified and a call for verification is initiated. These users would then report the validity of hotspot using their expertise in peat-firefighting (as a member of *Masyarakat Peduli Api*/Fire-aware community) or their local knowledge as a resident. This way, the validity of a report could be identified within minutes of a hotspot occurrence, and the disaster manager could rapidly determine if a hotspot is a real case of fire or another case of false alarm without

Table 1. Comparison with other crowdsourcing platforms.

Platform	Type of user	Data collection initiated by	Data overlay	Able to work offline?	Client-side app	Disaster response manager	Comparison highlight with Geocrowd
GeoCAN	Crowd as microtasker	System	High-resolution satellite imagery	No	None	GeoCAN Dashboard	GeoCAN users are team of experts, Geocrowd users are residents and in situ fire-aware community.
Houston Harvey Rescue	Crowd as sensor	User	USGS Crowdsensors (water depth)	No	None	Houston Harvey Rescue	Harvey is initialized through user report. Risk analysis is conducted during the aftermath.
TSER (Ushahidi)	Crowd as sensor	User	–	Yes	Ushahidi mobile	Ushahidi Dashboard	No initial data are provided to TSER/UShahidi users. Geocrowd can see nearby hotspots and other reports.
CROSS	Crowd as microtasker	User and/or system	–	Yes	'I Am Here' App	Crowdsourced map manager	No initial data are provided to CROSS users. Need continuous network connections (for route planning). Geocrowd can see nearby hotspots and SMS reports are possible.
OpenIR	Crowd as reporter	User	Medium-resolution preprocessed satellite imagery	No	None	OpenIR	Desktop users only. No restrictions on users regarding to information from satellite imagery.
Geocrowd	Crowd as microtasker (fire-aware community) and crowd as reporter (local residents)	User and/or system	Hotspot data from NASA	Yes	Custom-built	Geocrowd App	Geocrowd Analytical Dashboard
–							

conducting lengthy analysis such as clustering or proximity. This is the case with Houston Harvey Rescue (Yuan and Liu 2018), where data from crowdsensor (i.e. USGS water tables) are analysed against user reports (crowdsourced vulnerability and exposure) to identify the risk and eliminate the probability of a crying wolf.

At some extent, our approach in Geocrowd is similar to CROSS (Tsai et al. 2014). The system-driven CDC in CROSS is enacted by disaster manager after a disaster (e.g. earthquake) occurred in a certain area, while in Geocrowd, the hotspot-driven data validation occurred automatically for each hotspot with confidence >80%. In addition to hotspot-driven data collecting session, the Geocrowd also supports user-driven reporting for extreme cases where a fire occurred in a peatland area without being detected by satellite as a hotspot. Hence, the users' knowledge in peat fire precursors and characteristics is an important factor. Different from CROSS, Geocrowd users are local residents and fire-aware community equipped with satellite hotspot data as a precursor, thus are able to rapidly providing accurate information in a limited time. In contrast to CROSS which needs continuous mobile connectivity for route planning, Geocrowd is also able to send the report to disaster manager with limited network availability using SMS mode.

Geocrowd could also be compared to TSER (Liang et al. 2017) which used Ushahidi as a reporting platform. The ability to work offline by sending SMS is a common feature in both platforms. While TSER employs Open GeoSMS, Geocrowd uses customised encodings for its user SMS report (see Table 3). This is due to the characteristics of fire in peatland area, where small combustion in peat area could turn into an extreme fire within hours. Thus, the users should be able to report and validate the fire without having to be in the exact spot of the fire. In Geocrowd, it is implemented as user's self-estimation of distance and direction of the fire. The need to validate satellite hotspot data, send multiple data using limited means of communication, the ability to report on environmental conditions and gather all the information in the peatland area into an analytic dashboard is what TSER (and generally, Ushahidi) lacks. Hence, Geocrowd app and Dashboard are developed to fit the need in mitigating haze in the peatland area.

3. Research context and the study area

3.1. Research context

The design of users' on-site validation of crowdsourced geoinformation is challenging. Haze-mitigation actions demand more than just data collection (from satellite sensors and mobile sensors in this case). It needs collaboration mechanics for combining active and passive crowdsourced data for decision support.

This study focused on supporting the government initiative to eliminate haze problems and restore degraded peatland ecosystems. The system was designed to overcome problems found in peatlands, such as lack of telecommunication network coverage and socio-cultural characteristics of residents.

The Geocrowd reporting system consists of two main components: (i) an Android application for citizen fire reporting and environment monitoring, and (ii) a dashboard for decision makers and stakeholders to analyse reports and their influence in peatland areas. The Geocrowd Android application was developed to utilise citizen observations on fires as well as their severity for rapid response. The Geocrowd dashboard is used by government agencies, researchers and stakeholders involved in peatland management.

Both the Geocrowd mobile application and dashboard were utilised during the field study in Pulau Padang, Riau, Indonesia. Data collected from the field study were analysed using the dashboard and compared to the hotspot data from MODIS satellite and social media data on fires in Pulau Padang.

This 'Geocrowd' approach also supports water and peatland management so that the community and local farmland can be free of fires and haze problems. In implementing peatland restoration, water and peatland management are among the key drivers in eliminating haze problems (Dohong, Aziz, and Dargusch 2017). Such collaborative mapping, combining high-tech aerial sensor monitoring and human sensor monitoring, will be an excellent model to fight peat fires while supporting sustainable peatland management at the community level. The study area was a prioritised peatland restoration site, i.e. Pulau Padang, Kepulauan Meranti, Riau Province. The development and field test of an Android application for enabling community-based fire and haze mitigation is presented in subsequent sections.

The app development and field test aimed at proposing a village-centric solution for sustainable peatland management. The spatial data collected from the field can be used to develop community-based haze mitigation combined with hotspot and aerial imagery as an integrated mitigation system. Crowdsensing of environmental issues is seen as a promising data validation scheme since no information source can always generate reliable, up-to-date and accurate information about wildfire perimeters (Zhong et al. 2016).

3.2. Study area

The 110,888 ha of Padang Island, in Riau Province, North Sumatera, were chosen as the study area. Pulau Padang is a peat island located in Riau Province, Indonesia. It has a long history of peat fires. Big peat fires burnt down many areas of the island in 2014 and 2015. The fires caused problems for the local community and losses to the local farmers and the wood industry.

Land conversion and canal development for the wood industry were identified as the primary causes for the fires (Dohong, Aziz, and Dargusch 2017; Susanti et al. 2018). Figure 1 illustrates the relevance between hotspot patterns and the development of new canals. Massive canals were developed after 2009 when the central government issued a concession permit to utilise more than 40,000 ha of peatland in Pulau Padang for the forest industry.

The need for rapid-fire reporting in cases of peatland fires is evident from the most recent fire. According to interviews conducted in January 2017, during the 2015 Riau Peat Wildfire, at least five villages in Pulau Padang were affected. The area that is susceptible to peat fires has spread rapidly from the first hotspot occurrence. Owing to lack of communication, late response time and insufficient tools the fire could not be extinguished for nearly 30 days, with the subsurface peat fire lasting longer. Based on that experience, the residents of Pulau Padang have in recent years formed the 'fire-aware community/*Masyarakat Peduli Api*' to raise awareness on and improve preparedness in responding to fires.

As network coverage remains a significant problem for the island (and for many other peat islands in the country), relying on web connections to facilitate active crowdsourced apps do not offer a complete solution. In this case, mobile networks are mostly unavailable or somewhat limited. Thus, SMS reporting is also considered for this work. Ushahidi is designed to be able to send reports using SMS when mobile networks are unavailable due to disasters

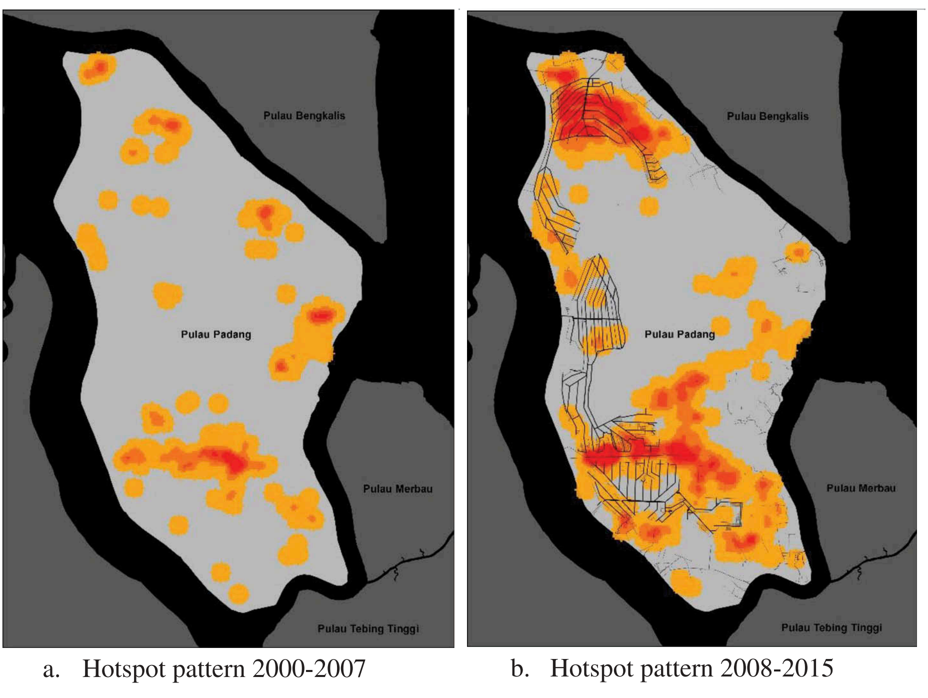

Figure 1. Hotspot pattern of Pulau Padang: before and after massive canals (represented by black lines) were developed for the forest industry.

or remote locations (Morrow et al. 2011; Okolloh 2009). This feature suits the need in peatlands, which are usually in rural areas. Geocrowd app adopts this ability to gather information in these low connectivity areas. The conceptual approach of Geocrowd is further explained in subsequent chapter.

4. Methods

4.1. Conceptual approach

In this research, we developed a peat fire reporting system called Liput Gambut (i.e. Peat Report). The term 'liput' suggests an activity to record, observe and report what happens to surroundings, in an attempt to prevent peat fires and haze. The conceptual approach to peat fire reporting and monitoring systems could be explained as in Figure 2. Users used the mobile app as a citizen reporting and validation interface. First, the application provided information on local hotspots in the users' vicinity using satellite data. The user could create a report on peat fires occurring near their position and validate the MODIS hotspot satellite data. The report and validation could then be sent to the dashboard for further processing and visual analytics.

The application detected available network signals in the area. If signals were unavailable, the application automatically switched to offline mode to send the report via SMS. A typical report from users included information such as pictures of the fire and severity. A panic button was provided for fires of the highest level, and its use suggested immediate action was necessary. The application could detect whether the user was located near the alleged hotspot based on satellite data. Then, the dashboard server would send a notification to allow the user to verify the hotspot. The validated and invalidated data could both be displayed and analysed in the dashboard and the application.

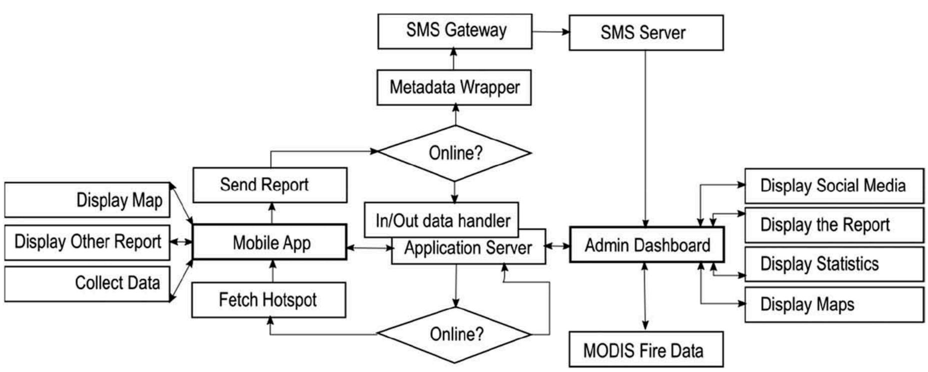

Figure 2. Conceptual approach of Geocrowd peat fire reporting system.

4.2. User requirements analysis

Requirements analyses were conducted through interactive interviews with residents in the study area in Pulau Padang, Riau, Indonesia, in January 2017. Requirements were also obtained from a literature review of published works and rulings regarding peatland area management. The user-facing application was designed with concepts similar to Ushahidi and was customised to meet the needs of a peat fire and peatland environment monitoring, such as:

(a) Ability to function with or without mobile network signals. For instance, using SMS-based reporting when signal availability was limited (e.g. when the only 2G signal was available) and network-based protocol when the network was sufficient.
(b) Quick reporting of fires (via panic button) as well as detailed reporting including radius and severity of fires.
(c) Visual indicators for validating satellite data. Users could estimate the severity of the fire at the moment of the report to infer the level of danger and damage caused by the fire.
(d) Automatic detection of new hotspots nearby so that users could visually ground-truth incidents of fire. This also served as a safety measure for users to make estimations without needing to be in the exact location.
(e) An easy-to-use interface that even the MPA or residents in other peat-land areas could utilise.

These five needs are realised into a Geocrowd app named Liput Gambut. This mobile application sends reports of alleged peat fires to the Geocrowd dashboard (http://geoinsight.ugm.ac.id/admin), which display the data overlaid with the MODIS satellite hotspot data. The dashboard also performed visual analytics on the data to provide information to decision makers. Figure 3 simplifies the data flow from the field through a Geocrowd app into a Geocrowd dashboard in the office.

4.3. Development of Geocrowd mobile app

4.3.1. Accuracy of severity

To determine the level of danger from peat wildfires, the Geocrowd application adopted the classification of wildfire severity provided by the Guidebook for Forest and Peatland Wildfire (Adinugroho et al. 2005). Based on the guidebook, levels of danger in cases of peat wildfires are classified as shown in Table 2:

The classes were incorporated in a GUI of the Geocrowd mobile app where users could estimate the severity of each peat fire. The accuracy of the reports was checked against other reports as well as with the confidence level of satellite-based hotspot data when available.

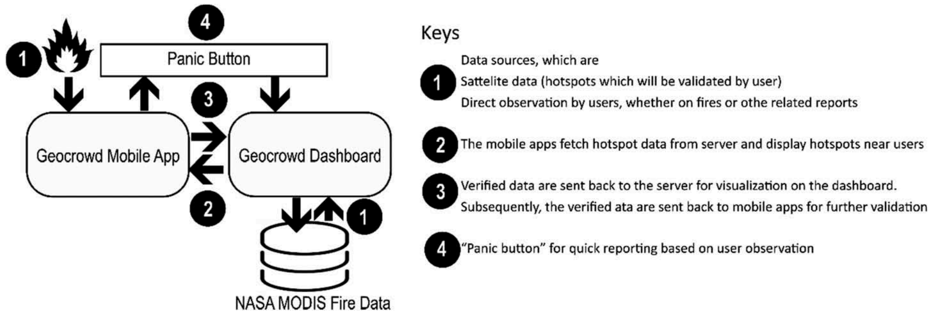

Figure 3. Logical data flow of the Geocrowd system of the app, named as *Liput Gambut*, and its dashboard.

Table 2. Severity of peat wildfire.

Classes	Characteristics of fire	Notes for firefighters
Low	Spreading surface fire	Ground fire only
Medium	Rapidly spreading surface fire of medium intensity	Fire can be contained using simple firefighting tools and water
High	Rapidly spreading fire with medium to high intensity	Powerful water pump or mechanical partition needed to fight fire
Extreme	Rapidly spreading high-intensity fire	Fire is very hard to contain, firefighting activities cannot be conducted at the forefront due to the intensity of heat

Table 3. Separator schema.

No.	Separator	Note
1.	L	At the beginning of the message; indicates that this is a report message
2.	V	At the beginning of the message; indicates that it is a verification message
3.	\`U\`	For user id data
4.	\`I\`	For incident id data
5.	\`A\`	For azimuth data
6.	\`K\`	For additional info data
7.	\`S\`	For severity data
8.	\`L\`	For latitude data
9.	\`B\`	For longitude data
10.	\`T\`	For date data
11.	\`P\`	For time data
12.	\`R\`	For verified report id data
13.	\`E\`	Signals the end of report
14.	\`E1\`, \`E2 , . . ., \`En\`	Signals the end of nth report

4.3.2. Radius, panic button and hotspot validation

Aside from estimating severity, the Geocrowd application also supported radius for hotspot verification. The user could set the radius for estimation at 0–5 km from their current location. The 5-km limit was established based on interviews with residents in the study area, given the average distances they cover in the course of their daily activities.

The selected radius was represented as a circle around the user. TurfJS library was used to perform spatial analysis (i.e. 'within' the identified circle) on the satellite-based hotspot so the user could verify it. This ensured that the user only verified satellite-based hotspots visually accessible to them.

For extreme fires where danger was imminent, the Geocrowd app provided a shortcut, namely the 'panic button'. It could be used to send an immediate report to the dashboard app with pre-set fields for extreme danger. This breaks the usual report-verify cycle and was preconfigured to use an encoded message via SMS for rapid reporting.

Feedback for user validation of hotspot data, as well as satellite hotspot data, was sent back to the user and displayed in the Geocrowd App. The GeoJSON format of the data used in the app was built using LeafletJS library. Updates were obtained using AJAX and PHP Long-Polling, which checked if updates were available in the NASA MODIS server based on the hotspot's timestamp and subsequently updated the existences of the nearby hotspot when available.

4.3.3. App development

The Android application design was modelled as a UML diagram. The actors involved in the use-case diagram were divided based on the status of the user, i.e. registered or public. Unregistered/public users were defined as Geocrowd app users who had not logged into the Android app, while registered ones had logged in. Both these users had different rights to access features available within the Android app (Figure 4).

The Android app mockup was created using the Inkscape Software. The Inkscape software was used to plan the position of visual elements displayed on Android applications, to design navigation of the application and to perform user tests on the design. This preliminary design was later used as a benchmark in the manufacture of the application code. The navigational design is shown in Figure 5.

The Geocrowd Android app was developed using Ionic Framework. Ionic is an MVC framework designed for multiplatform mobile application development using web technologies, i.e. HTML, CSS and Javascript. Aside from the multiplatform benefit, the Ionic Framework was chosen for the Geocrowd mobile app development for its support on Android and iOS hardware via PhoneGap Plugins.

4.3.4. SMS report

As mentioned earlier, when the user's internet signal was inadequate, a report on fire occurrence would be sent to the server using SMS instead of mobile internet. The coordinates of the report location are gained from mobile device's internal GPS (Global Positioning System) sensor. The Geocrowd app would compose the text and attach location data. When this method is enabled, information entered by the user on the reporting form would be encoded into plain text format separated by certain characters to be interpreted by the Geocrowd Dashboard. The separators were detailed in the following table (Table 3).

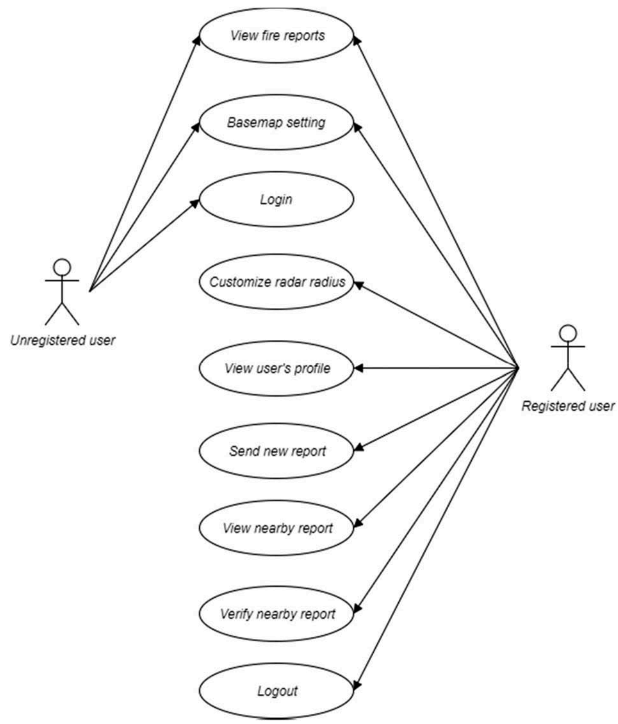

Figure 4. Use-case diagram for Geocrowd app.

Examples on the use of such separators in report submissions are as follows:

- Case 1 (report length <160 characters)

  L`U`user_5924cf33a3bd3`I`1`A`0`K`Severe fires occurred near the canal `S`8`L`2.084`B`101.644`T`2017-05-29`P`1015`E`

- Case 2 (report length >160 characters)

o First SMS:

  L`U`user_5924cf33a3bd3`I`1`A`0`K`A severe fire occurred near the main canal, required immediate relief. Expected to bring hoses, buckets and other equ`E1`

o Second SMS:

  `E1`ipment`S`8`L`2.084`B`101.644`T`2017-05-29`P`1015`E`

This codification was done automatically by the apps before sending the report to the server via the SMS gateway. The first thing the server did when it received this SMS report was to check whether it had an 'end of report' sign or not. When the end of report sign was absent, the server would keep the report in temporary storage while waiting for the rest of it to be sent. When all parts of the report had been received, the server would concatenate the sections,

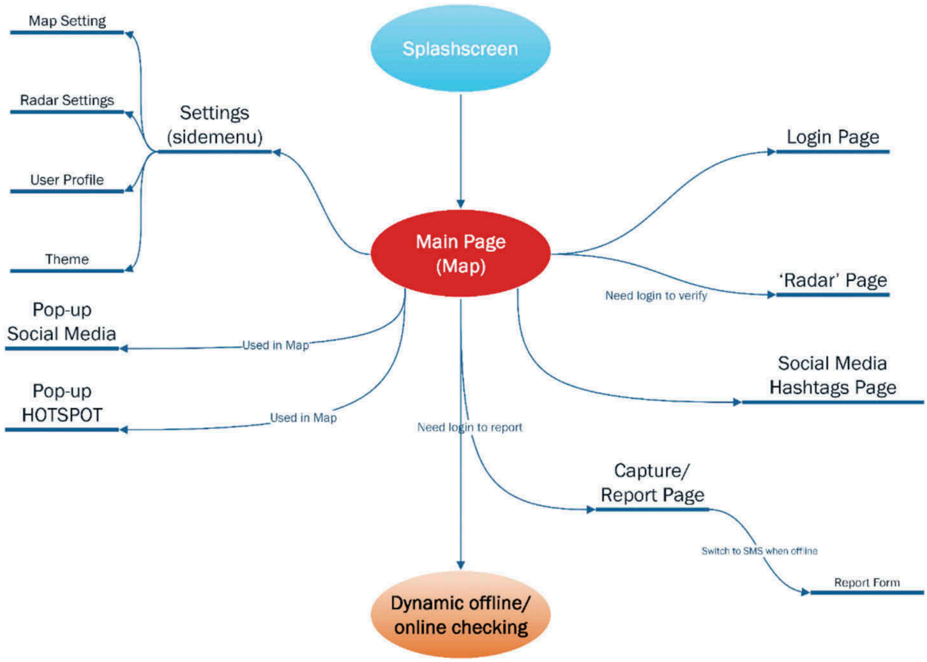

Figure 5. Information workflow of application interface design.

extract existing information utilising the schema shown in Table 3, and store the report in the database. These cycles are depicted in Figure 6.

4.4. Development of Geocrowd dashboard website

The Geocrowd Dashboard was designed to be used by stakeholders and government initiatives for visualising near-real-time hotspot data from MODIS satellite (https://firms.modaps.eosdis.nasa.gov) and fires reported by direct observation from the user's mobile app. The dashboard also displayed the hotspot data already verified by users via the Geocrowd app.

Geocrowd Dashboard was developed using CodeIgniter MVC framework and LeafletJS map library and utilises MySQL for the database. The database's conceptual design consisted of 10 entities related to peat wildfire and is represented in the class diagram in Figure 7.

Two actors were defined in the dashboard use-case diagram: the administrator and the system user (see Figure 8). The administrator was an authenticated user who performed the analysis and visualisation in the Geocrowd dashboard. The system user referred to an autonomous system developed using PHP via CodeIgniter framework. It ran in the background, updating satellite hotspot data.

The MVC concept in CodeIgniter (Upton 2007) was implemented as models, views and controllers that ran the dashboard application seamlessly. LeafletJS,

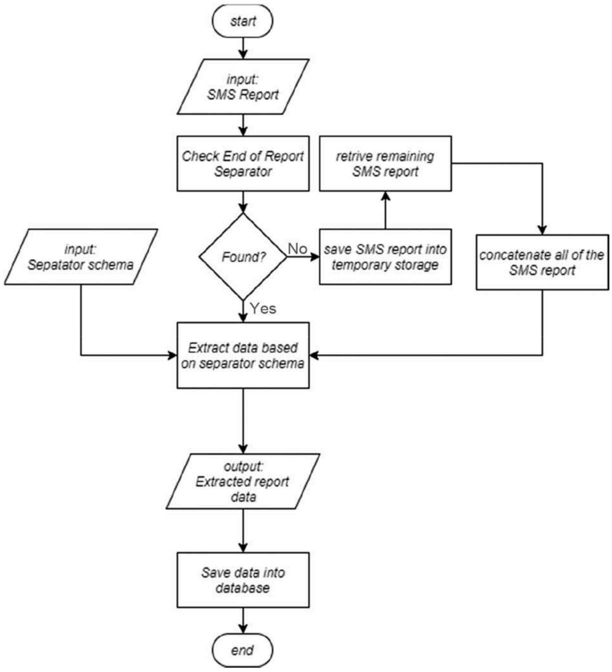

Figure 6. Flowchart for handling SMS reports in the server.

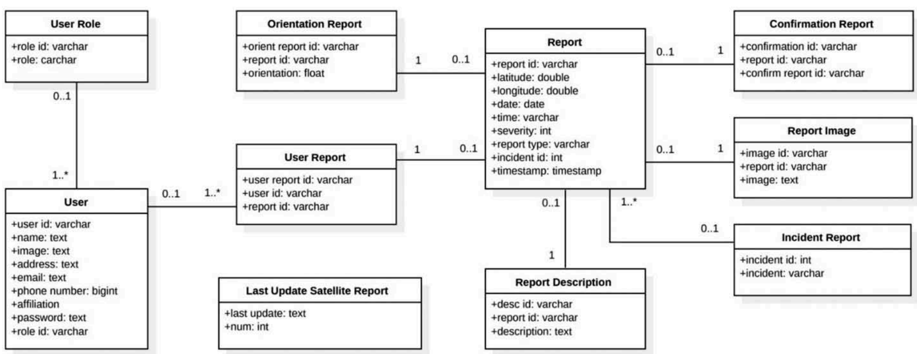

Figure 7. Database schema of Geocrowd's dashboard.

an open-source Javascript library for web maps (Agafonkin 2018) was employed for base map tiling and applying visual analysis to the data, resulting in heat map and marker cluster visualisations. Heat maps were used to display user reports, while marker cluster function displayed animated hotspot data distribution. Geospatial analyses were conducted using TurfJS library (http://turfjs.org/), which performed spatial aggregation of hotspot data against administrative boundaries in the study area. In this case, the study area focused on administrative areas related to Padang Island in Riau and neighbouring provinces in Sumatera that had similar problems with peat fire

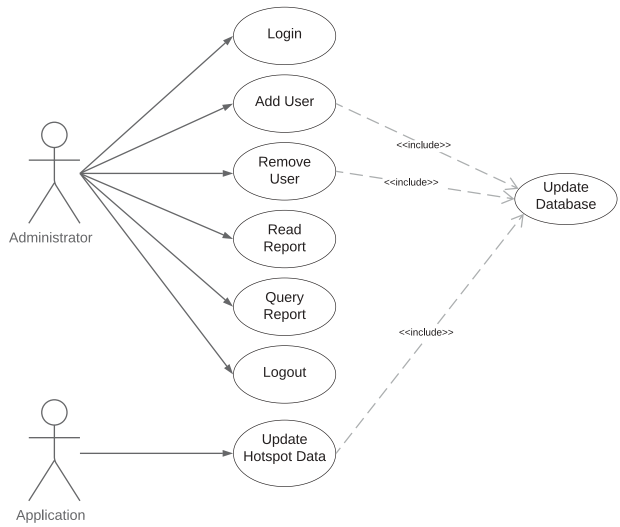

Figure 8. Use-case diagram for Geocrowd's dashboard.

and haze. The results were illustrated in a graphic plot that displayed the trends of hotspot data and validated hotspot, as well as reported peatland parameters obtained through the Geocrowd Apps.

5. Results

5.1. Geocrowd mobile apps

Mobile apps must be usable in remote locations where telecommunication networks might be minimal. Thus, typical users, local residents or farmers should be able to use the SMS or Web-based reporting services when telecommunications networks were inadequate while fighting fires to protect their farms or properties. When NASA's MODIS fire database is updated with new hotspots, the Geocrowd app would be updated as well, showing location of these hotspots. If the hotspot situated nearby a user, a field validation report would be enabled to the user, and the validation report would be sent to Geocrowd dashboard. The targeted users of this application were members of the fire-aware community and village leaders. New user who wants to be a volunteer needed to register to be able to validate a hotspot. The registration process was simple and members of the fire-aware community and village activists could do it. The user profile they entered was important for central responders in the data centre to directly contact trusted, registered users in case of fire emergencies (Figure 9).

Once Geocrowd users logged into the application, alleged hotspot from satellite data would be delivered to them as well as interactive radar view. Instead of fixed-range radar view, the app allowed users to change the

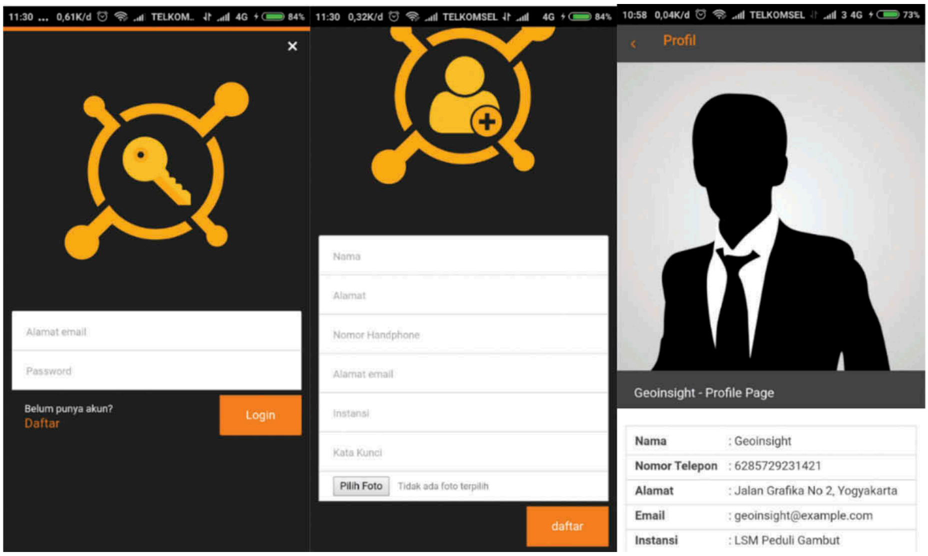

Figure 9. Registration page in the app interface and user-management menu in the dashboard.

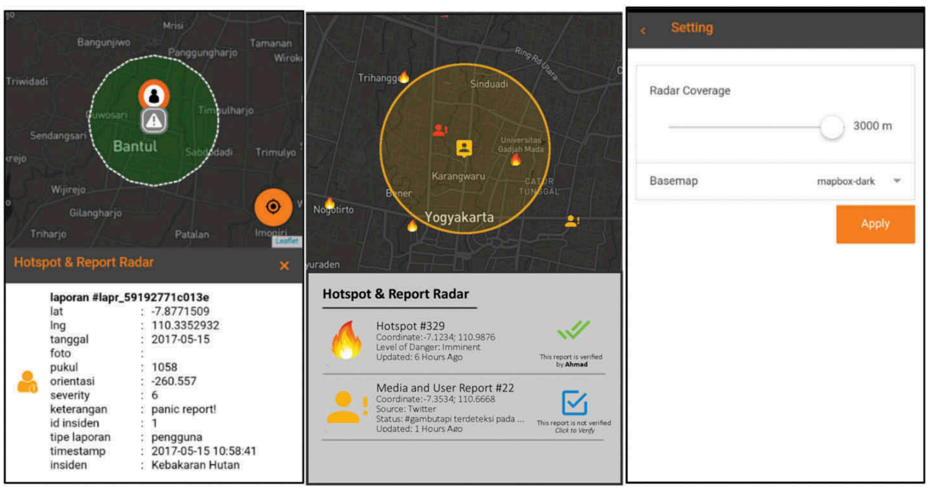

Figure 10. New hotspot indication from the system displayed in a radar view.

buffer distance of the radar (Figure 10). Hotspot data from the satellite and other user's report were displayed in the Geocrowd app, with different marker symbols for both items. Validation could only be conducted when these markers falls within the radar, whether on hotspot data or other user's report. Thus, users could work together to update information and ensure it was correct. They could correct either the hotspot fetched by the app or other users' reports on peatland issues within the radar (Figure 10).

Users were able to use a normal reporting button or if they felt an immediate report was needed, they could use the panic button. A report using the normal button accommodated incidents of fire, illegal logging, canal development, or any other environmental disruption. During interviews, residents confirmed that these three were environmental issues affecting their livelihood. Thus, the main reports that could be facilitated in the app were targeted to deal with these issues:

- Mitigating and stopping fires since farmland in the forest is a source of livelihood.
- Mitigating and stopping illegal logging activities. Selective cutting of trees for repairing houses and building new homes is threatened by illegal loggers who cut down all trees without discriminating.
- Curbing canal development (see Figure 13). Acknowledged as an efficient way to prepare cropland and to transport forest yields, canal development also results in flooding in many areas during the rainy season while other areas dry up easily because of canal management under concessions.

The user interface for submitting new reports is shown in Figure 11. It also included possibilities to geotag photographs of the on-field situation.

A severity indicator allowed users to make field assessments regarding the severity of incidents based on their personal view and experience (see Figure 12). Severity here can be linked with fire indicators such as haze or smoke, as well as the distance to the user.

As villagers and activists made reports from the field, the data were stored in the server and disseminated to other users. The symbols used are presented in Figure 14.

At the time of drafting this paper, the Geocrowd:Liput Gambut app had been published through Google Play and was available for download and use, but the data report could not be tested as the area had been relatively free of peat fires.

5.2. Geocrowd dashboard

Geocrowd was used to monitor and filter data from satellite sensors and from citizens on the ground. It was also used to support data aggregation based on administrative boundaries. This is important because fire management is commonly delegated to village and district leaders. Community-based firefighters in villages in peatlands work based on village or district administrative boundaries.

As seen in Figure 15, the basic map displayed the raster format of peat depth distribution, reports and hotspot data. The classes of peat depth were taken from the official map of the Ministry of Agriculture on the distribution and depth of peat. The depth information was important because regulation mandated preserving peat of depth greater than 300 cm from exploitation by

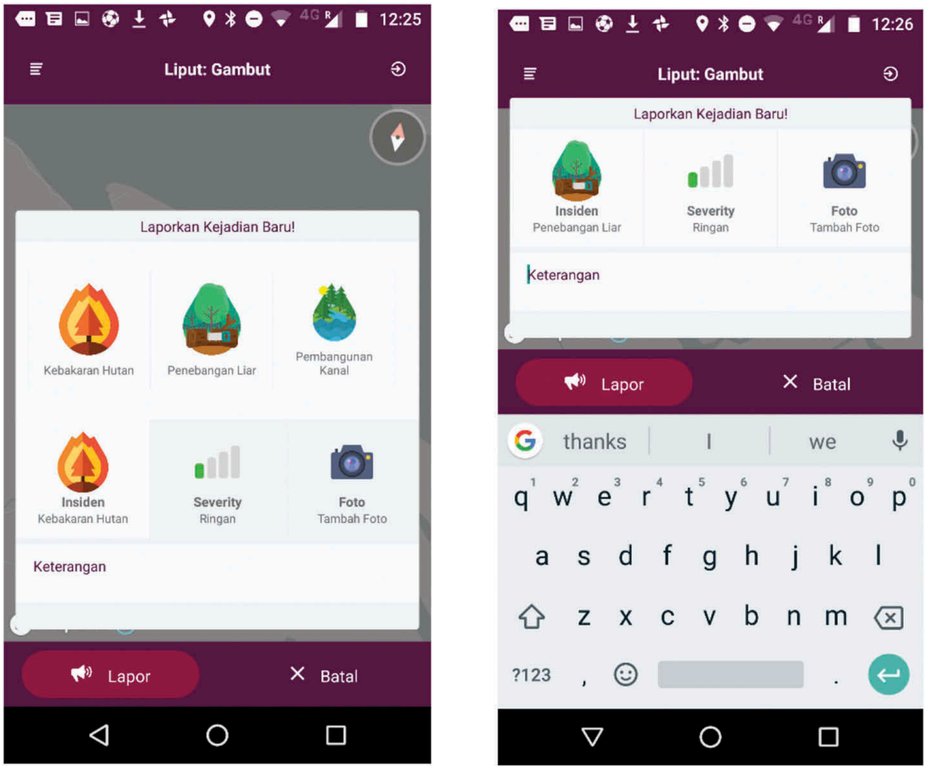

Figure 11. An interface to facilitate citizen participation for reporting fires, illegal logging, and canal developments.

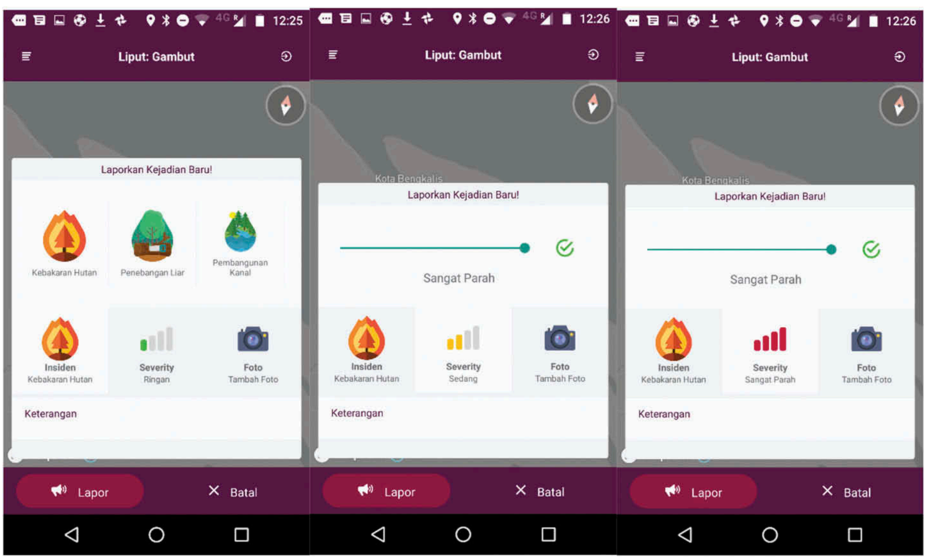

Figure 12. Severity adjustment range – low, medium, and high severity.

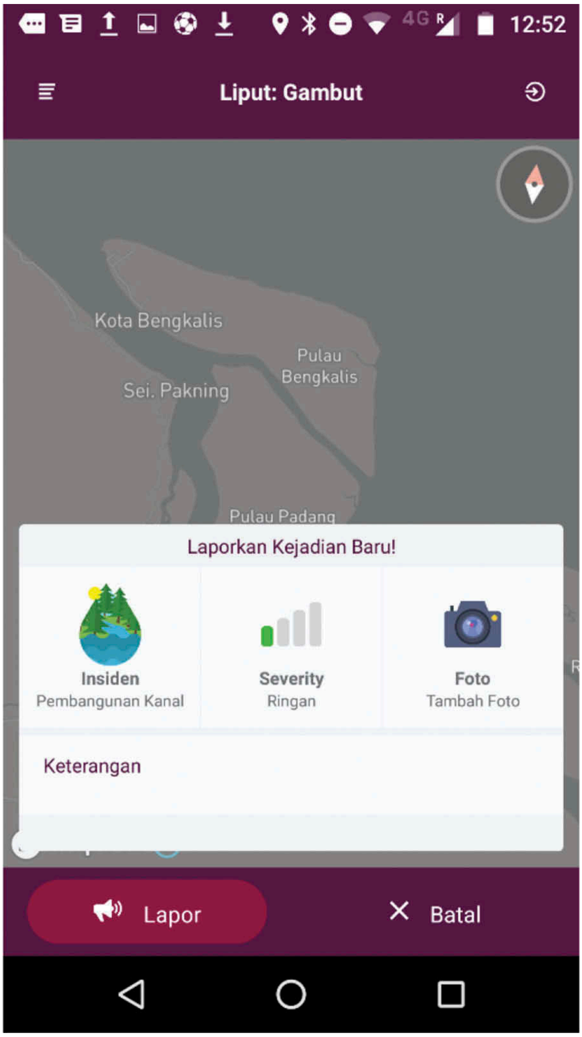

Figure 13. An interface to make a report of new canal developments.

agriculture and industry. The reports from community and crowds were displayed as heat map visualisation, informing dashboard users of the intensity of reports by converting individual report data as a point on the heat map. Then, the hotspot data were displayed as proportional circle symbols indicating the number of hotspots in each district (see Figure 16).

Hotspot aggregation was used to group reports from users and hotspot data into district administrative areas. This data grouping was useful in coordinating the actions of community-based firefighters in the district. As seen in Figure 16, the more the fires in the district, the bigger the red circles on the map. When dashboard users zoomed into the area or clicked on a circle, it was divided into proportional circles within the selected area.

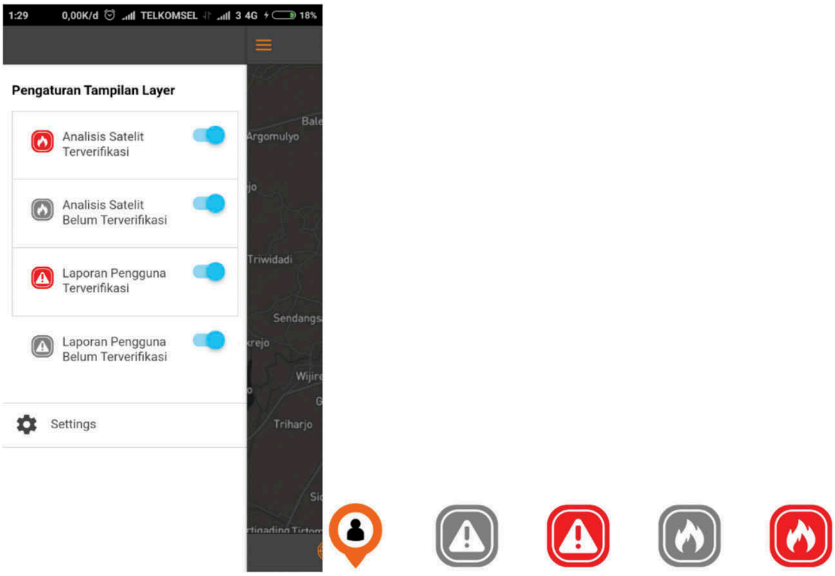

Figure 14. Options for display and corresponding symbols displayed on the screen.

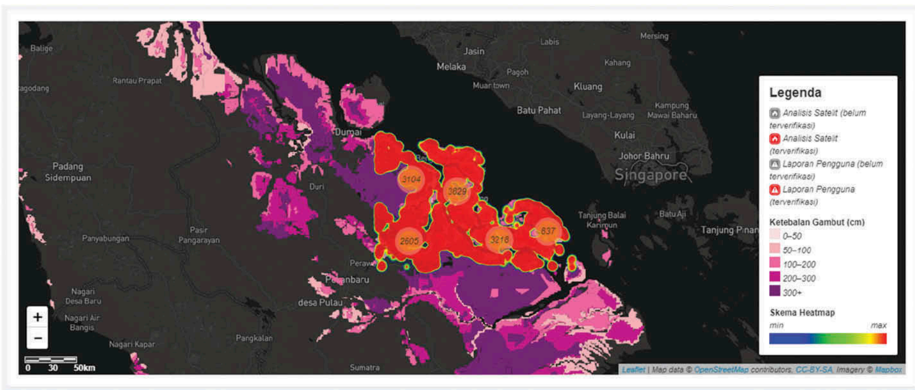

Figure 15. Map visualization and hotspot aggregation.

Beside the map interface, the dashboard displayed users and data statistics (Figure 17). The dashboard could be used to check and control user profiles. Basic user activity of users could also be monitored from the dashboard. Data analytics on the dashboard eased monitoring of reports and hotspots (Figure 18). The hotspot aggregation was available as a tree view and also displayed as graphics. The plan was to include water table sensors on the field to get a better view of the trend of water and hotspot correlation. As data communication of water table stations via internet and SMS is difficult, if not impossible, manual data integration was used instead. At present, the water table data (and other *in-situ* sensor data in Pulau Padang) cannot be displayed on the dashboard site.

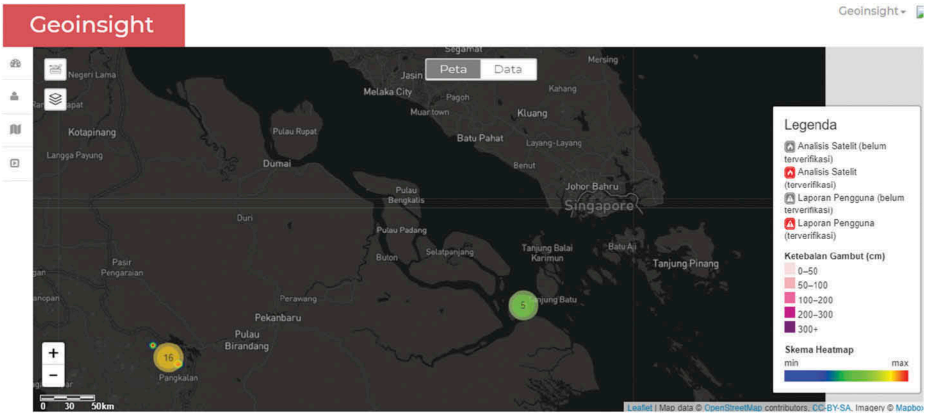

Figure 16. Map visualization and hotspot aggregation.

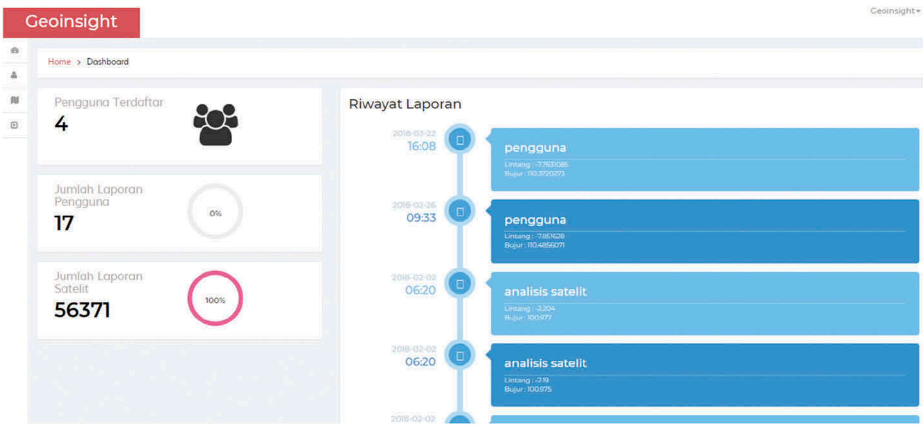

Figure 17. User and data statistics.

6. Discussion

6.1. Problems with app

The main obstacle to obtaining data through the Geocrowd app was the availability of mobile network signal. The majority of peatland in Indonesia which commonly located in either outer or almost inaccessible land of the country has poor cellular network reception. For areas with limited connectivity, strategies implemented in Geocrowd app could be used to tackle the issue, i.e. sending reports as SMS, which are then converted to user reports in Geocrowd dashboard. However, this strategy still relies on the availability of 2G network to process SMS. In remote peatlands, where network availability is extremely low or even non-existent, this method would not work. Instead, reports could be stored locally on the user's mobile device and sent once network signal is available. This approach also has a limitation: the reports

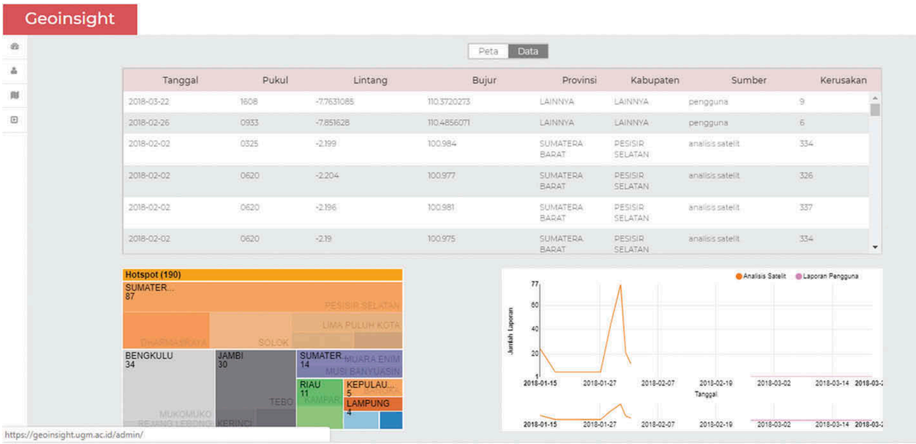

Figure 18. Data table of events and reports (top); tree view (right bottom) and graphics (left bottom) of hotspot data.

submitted to the dashboard would not be near real-time; thus, analysis might not be available when needed.

Another problem that relates with limited cellular signal availability in those areas is that satellite data sent to users from the Geocrowd dashboard would not be available. Thus, users 'near' an alleged hotspot location might not be able to identify and validate the hotspot report. Even when the cellular signal is available, a really accurate hotspot validation is constrained with 'safety in mind' consideration. As satellite hotspot's spatial resolution is less than a thousand meters, a validation report which has a distance less than 500 m would be considered fair enough.

Updates on user's mobile devices depend entirely on network connectivity, at present no other strategies are available other than improving network availability in the area. As satellite communication would be too expensive to serve many peat islands, which commonly have flat topography, government and business intervention to develop wireless approaches such as low-cost Wi-Fi Antenna and Mesh Wi-Fi Network for rural areas could be implemented (Hameed, Noor, and Junaid 2018; Ishmael et al. 2008; James 2010).

6.2. Problems with dashboard

The Geocrowd dashboard is built on MySQL to store satellite data and user validation reports from the Liput Gambut app. Increased hotspot data and user reports demand more storage as well as the ability to perform analysis on the data. Thus, a Big Data approach is needed for efficient storage, management, analysis and visualisation of the data. Currently, satellite hotspot data are obtained from NASA Hotspot data on a daily basis, while user reports are stored immediately in the database. It is possible to develop spatial Big Data infrastructure on top of the current approach and slowly migrate the contents without affecting users accessing the Geocrowd dashboard.

6.3. Usability issues: tracking the hotspot

Present strategies for user validation on alleged satellite hotspot data involve providing users with an interface to estimate fires near their location. However, this approach has some limitations: 1) hotspot location accuracy might not be available when users submit their reports, since validation is conducted relative to user's location and relies on their perception of distance and severity; 2) since validations are performed using visual cues (with users seeing the signs of a fire, e.g. smoke or haze), under some conditions users might report an alleged hotspot as false because their vision is somehow impeded; 3) false alarms could be raised if the hotspots detect man-made fires (such as open-air burning) and users seeing the smoke report them as peat fires.

The strategies in Geocrowd Liput Gambut App are implemented with user safety in mind. Peat fires might spread very quickly, and residents should be able to reach a safe location as fast as possible, while being able to submit reports to authorities for immediate action. False alarms would be eliminated if more users observed the same alleged hotspot and reported correctly on fires.

7. Conclusions

We have proposed an approach to effectively detect and validate hotspots indicating fires in rural areas, especially in peatlands where fires could cause extensive damage. By combining the massive data obtained from satellite monitoring (i.e. alleged fires or hotspots) with the ground truth approach by crowdsourcing user validations, immediate action on fires could be initiated earlier, thus preventing more damage. The data collected from satellite detection as well as ground-truth data from user reports could provide decision makers valuable insights on fires, especially in peatlands. The strategies implemented in the Geocrowd app and the Geocrowd dashboard could be replicated in other rural or remote areas, through crowdsourcing and validating data where signal availability is poor. The app depends on community leaders' awareness and participation. As shown during the field test to community leaders, community participation is essential to generate cost-effective haze mitigation. The study showed the potential use of mobile apps for local communities to help the government validate hotspots for haze mitigation and environmental protection. The platform could be used by decision makers to gain insights on fires and to mitigate disasters, especially in tropical peatland areas.

Disclosure statement

No potential conflict of interest was reported by the authors.

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