Steps towards the development of a Peat Fire Danger Rating System in Indonesia

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Abstract. Fire danger rating systems (FDRS) are a critical tool, used around the world to help predict and prevent wildfires. Forest and land fires are a severe problem in Indonesia, with smoke and haze production exacerbated by the country’s extensive tropical peatlands, many of which are drained and burn almost annually. The Indonesian FDRS was established in 1999 under the Meteorological, Climatological, and Geophysical Agency, in partnership with other government agencies, and is largely based on atmospheric data. Indonesia’s FDRS differentiates land types, including peatlands, but only predicts surface fire risk, rather than the risk of peatland surface fires becoming below-ground peat fire – which emit greater amounts of haze-producing smoke. This study proposes how Indonesia’s FDRS might be further developed to include below-ground peat fire risk. This was achieved based on consultation with government agencies which manage and provide data to Indonesia’s FDRS, and the establishment of a Peat FDRS Stakeholder Engagement Network. We describe which biophysical, social-economic or atmospheric input variables are needed in such a model to quantify the peat fire risk. We present what field data is currently available (e.g. weather) and which factors require additional data collection, including some aspects of land and social data, and, notably, bio-physical ground data on fuel loads and fuel moisture content. Data is presented by type, historical availability, scale and reliability, presented in a visually clear colour-coded table. This information can support the development of a specific peat fire risk section within Indonesia’s current FDRS.

1. Introduction

1.1. Development of Indonesia’s FDRS

Indonesia’s fire danger rating system (FDRS) development began in 1999 working across multiple Indonesian government institutes, specifically, BMKG (Meteorology, Climatology, and Geophysical Agency), BPPT (Agency for the Assessment and Application of Technology), LAPAN (National Institute of Aeronautics and Space) and KLHK (Ministry of Environment and Forestry), together with the Canadian Forest Service (CFS) [1]. The system was based upon the Canadian Government’s FDRS, which used four main data input factors: precipitation, air temperature, air moisture and wind speed and...
direction [1]. The system, based largely on atmospheric data, could be used to provide an output index, or danger rating level, but it was acknowledged that it needed to be verified and calibrated through additional on-the-ground input data, collected in the field, not only remote weather stations [2–4]. Over the subsequent years, the above institutes worked to increase data input and verification. Consequently, the resolution and the accuracy of the model have been improved in the subsequent years (Figure 1), culminating in the SPARTAN FDRS developed by BMKG. SPARTAN provides input variables of Fine Fuel Moisture Code (FMMC), Duff Moisture Code (DMC), and Drought Code (DC), and dependent variables of Build-Up Index (BUI), Initial Spread Index (ISI), and Fire Weather Index (FWI), that operates with up to 7 days prediction capability and 11 km resolution [5] (Figure 2).

![Implementation](image)

*Figure 1. History of the development of Fire Danger Rating System in Indonesia (Source: BPPT, MoEF, BMKG, LAPAN).*
In addition to the core FDRS functionality as described above, other aspects within the FDRS algorithm are being developed, including human factors and/or characteristics of peat, by BPPT (Ina-FDRS) and BRG (Peatland Restoration Agency). Several agencies are also working to implement an early warning system for fire events, which is expected to be able to complement the existing FDRS, namely in the form of a Fire Risk System. This risk system is built based upon climate data which is more seasonal in nature and is intended to predict the level of risk of fire events on a monthly or 6-monthly basis. This has been developed by CCROM-SEAP IPB (Fire Risk System) and the BMKG Research and Development Center, titled the Climate Index for Suitability of Hotspots Occurrence [5]. This interactive collaboration between agencies is a key aspect of a successful FDRS [7].

1.2. Need of a peat FDRS in Indonesia

Indonesia has one of the world’s greatest extent of tropical peatlands [8], and are of global critical importance in terms of their environmental services, notably carbon storage [9]. Much of these peatlands are now degraded through drainage, logging and industrial plantation development [10,11]. Subsequently, forest and land fire events have become a massive, almost annual problem for Indonesia [12,13], with five major fire events taking place over the last four decades (1987, 1997, 2006, 2015, 2019) [14]. When these fires occur on tropical peatlands and, then, if they transition to the peat itself ignites, which are extremely hard to extinguish, and result in toxic, polluting haze [15,16] which can blanket the region, causing disruption, cost and health impacts [17,18]. Therefore, although non-peatland wildfires can also be hazardous and should be prevented, and surface peatland fires create the risk of the peat igniting, it is once the peat itself ignites that emissions and pollution become so damaging [15,19]. It would therefore be highly beneficial for Indonesia’s FDRS to be able to distinguish between
non-peatland fires, peatland (surface only) fires, and peat fires. This would facilitate improved targeting of hazardous fires and lead to better and more appropriate fire management.

1.3. FDRS structure

Fire Danger Rating Systems (FDRS) are designed by having a series of input variables which all play a role in influencing the response variable severity. The response variables are factors which are used to show the severity of the fire. The input variables are the factors which influence how great the response will be. The relationship between input and response variables needs to be verified with data to show the accuracy and predictive ability of the relationship. Multiple input variables or factors combine together to result in the response [20]. A table with some example inputs and response variables is shown in Figure 3. The resolution and accuracy of an FDRS is dependent on what data is available to feed into the model, and how well tested the relationships are between the inputs and dependent variables and the weighting of each input variable [21].

![Figure 3. Example input variables (circled red) and dependent variables (circled blue) and how these interact (circled purple)](image)

1.4. Objectives

Based on the structure of the current FDRS in Indonesia and the data that is currently available to feed into it [5], this paper considers what additional data sources would be needed to include a peat fire danger rating index into this system. We present the availability of this data, the scale required, and whether the relational validity and weighting is known. We highlight areas that require further research and suggest direct next steps to meet these knowledge gaps.
2. Methods
Two approaches to knowledge acquisition were implemented. The first was to conduct one-to-one interviews with all the institutes which were involved in the development, running and usage of Indonesia’s FDRS. This included BMKG, BPPT, LAPAN and KLHK. The second was to establish a PFDRS Stakeholder Engagement Network. Within this, all relevant stakeholders and academic institutes working in this space, such as BMKG, BPPT, LAPAN and KLHK, the Peatland Restoration Agency (BRG), the Agricultural Institute Bogor (IPB), the Food and Agriculture Organization (FAO), and World Bank were invited to participate in regular (biannual) events. At the events research, knowledge, progress and future plans were discussed in an open and collaborative space.

Based on the results and discussions from both these approaches, a list of most likely PFDRS input variables was established. The data availability for these variables was collated based on resolution, scale and duration of time. The degree of relational weighting of each variable established within the system was also recorded, as well as the institutes which collected, collated or managed the data. This information was developed into a colour-coded table to highlight the availability of the data (Table 1).

### Table 1. The colour coding system applied to summarise availability of data to be used as input variables to Indonesia’s peat fire danger rating system

| Colour | Data availability (of verified and reliable quality) | Relational weighting within a (P)FDRS | Scale at which data is available (represented by shade) |
|--------|-----------------------------------------------------|--------------------------------------|-----------------------------------------------------|
| Green  | Available, accessible and analysed                   | Well established                     | Regional (dark green) Case-study (pale green)       |
| Yellow | Available but not yet analysed                      | Not yet established                   | Regional Case-study (pale yellow)                   |
| Orange | Collected but not accessible to analyse             | Not yet established                   | Regional (dark orange) Case-study (pale orange)    |
| Red    | Not yet collected                                    | Not yet established                   |                                                     |

3. Results and Discussion

3.1. Key findings
A total of 23 input factors were proposed as potentially influencing the PFDRS dependent variable of peat fire incidence, covering variable groupings of weather (six variables), land (four variables), social (six variables) and biophysical (seven variables) (Table 2).

Weather data (temperature, relative humidity, wind speed, rainfall, wind direction and ENSO data) was very well represented. The data is collected and managed by the BMKG. Both historical and national-scale data was available. The relational importance of these data sets had also been established within Indonesia’s FDRS. The data availability for the land and social groups (land cover, hotspot presence fire history, and land condition, and, population, settlements, access routes, livelihoods, economic activity and culture, respectively) were more mixed. Data with a long historical record, such as land cover, hotspots and settlements were collected at a national-scale, and their relational importance within the FDRS was well established. Other data, on fire history and livelihoods, were available, but their relational importance within the FDRS was understudied. There was no data available for land condition and culture. The fourth grouping involving bio-physical data sets, i.e. those collected directly in the field, included canal infrastructure, water table depth, fine fuels, peat moisture content, peat,
surface fuel flammability, and peat decomposition levels, were the least well studied. Other data sets had been collected but their relationship within the model had not been established.

It should be noted that three factors, livelihood, economic activities and water table depth, appear in the Table 2 at two points; first as yellow colour-coded, and then red. This is because some data has been collected and is available on these factors, but the data has been collected in a way that is not highly compatible to use within an FDRS model. Consequently, more strategically designed methods and data collections are required. It is encouraging to note that no data sets were colour-coded orange – i.e. collected but not made available, which indicates the high degree of collaboration that exists between the multiple institutes involved, listed in the table as data contributors.

3.2. Steps forwards

This summary information and highly visual colour-coded system (Table 2) highlights easily which data is lacking and requires additional research. All input variables which have been colour-coded red have possible next-step methodologies provided in the table. These include: developing fire degradation forest categories to better describe, quantitively, the land condition at different stages of degradation due to and recovery from fire. Questionnaires could be specifically designed and implemented to collect data on livelihood, economic activities and culture. Data on the whole peat dome water table depth is needed; as well as field sampling and controlled laboratory analysis to describe fine surface fuels and peat moisture content, and spatial and temporal samples of forest-fire history categories, with a particularly focus on sampling diurnal and dome-wide peat moisture content.

Once this data is able to be collected and made available, the next step would be to establish a PFDRS model. Using historic data to run the model, the relational importance of each input variable could be correctly weighted, and then prediction ability could be trialled to assess accuracy and calibrate the model. This operational model could then be applied in the field to improve peat fire management approaches.

One output of this research process has been the establishment of the PFDRS Stakeholder Engagement Network (SEN) as described in the methods. Events were held in September 2019, January and November 2020 and the next SEN event is planned for October 2021. At each event we have had 15-30 participants from at least ten institutions that have participated actively, contributing knowledge, ideas and progress. One of the key findings of this research is the complexity of data that are needed to complete a PFDRS operational model, and that these data cover a range of methodology types and disciplines, from climate and remote sensing, to social and biophysical. Having a strong, collaborative network with a shared understanding and research direction provides a route to achieving this complex goal.
Table 2. Data availability for establishment of a Peat FDRS in Indonesia

| Variable grouping | Input variable       | Data status (colour code) | Historical data available (10+ yr) | Data source | Method                                                                 | Type of Data |
|-------------------|----------------------|---------------------------|----------------------------------|-------------|------------------------------------------------------------------------|--------------|
| Weather           | Temperature          | Dark green                | Yes                              | BMKG        | Collected from national weather stations, remote sensing              | Numeric      |
| Weather           | Relative Humidity    | Dark green                | Yes                              | BMKG        | Collected from national weather stations, remote sensing              | Numeric      |
| Weather           | Wind speed           | Dark green                | Yes                              | BMKG        | Collected from national weather stations, remote sensing              | Numeric      |
| Weather           | Rainfall             | Dark green                | Yes                              | BMKG        | Collected from national weather stations, remote sensing              | Numeric      |
| Weather           | Wind direction       | Dark green                | Yes                              | BMKG        | Collected from national weather stations, remote sensing              | Numeric      |
| Weather           | ENSO                 | Dark green                | Yes                              | BMKG        | Collected from national weather stations, remote sensing              | Numeric      |
| Land              | Land cover           | Dark green                | Yes                              | MoEF        | Remote sensing, terrestrial surveys                                    | Spatial      |
| Land              | Hotspot presence     | Dark green                | Yes                              | LAPAN       | Remote sensing, field observations                                    | Spatial      |
| Land              | Fire history (burnt area) | Dark yellow            | No (2017 up to <2015 (every 3 yrs) >2015 (more routine)) | MoEF        | Field observations Remote sensing (Landsat)                           | Field measurement |
| Land              | Land condition       | Red                       | No                               | New research required | Fire degradation forest categories established | Field measurement |
| Social            | Population           | Dark green                | Yes                              | BPS         | National census                                                        | Numeric      |
| Social            | Settlements          | Dark green                | Yes                              | BIG         | Remote sensing, field surveys                                         | Spatial      |
| Social            | Access route         | Dark green                | Yes                              | BIG         | Remote sensing, field surveys                                         | Spatial      |
| Social            | Livelihoods          | Dark yellow               | Yes                              | BPS         | Interviews, secondary data review (Not specific to FDRS)               | Observation  |
| Social            | Economic activities  | Dark yellow               | Yes                              | BPS         | Interviews, secondary data review (Not specific to FDRS)               | Field measurement |
| Category       | Variable                      | Status      | Research Needed | Methodology                                                                 |
|---------------|-------------------------------|-------------|-----------------|-----------------------------------------------------------------------------|
| Social        | Livelihood                    | Red         | No              | New research required                                                       | Interviews using specifically designed questionnaires for PFDRS |
| Social        | Economic activities           | Red         | No              | New research required                                                       | Specifically designed questionnaires for PFDRS |
| Social        | Culture                       | Red         | No              | New research required                                                       | Specifically designed questionnaires for PFDRS |
| Biophysical   | Canal infrastructure          | Dark yellow | No (2016 up)    | BRG                                                                         | Remote sensing, GIS, surveys |
| Biophysical   | Water table depth             | Dark yellow | No              | BRG (Sipalaga), SESAME (JICA), dip well (BRG)                               | Spatial, numeric |
| Biophysical   | Water table depth             | Red         | No              | New research required                                                       | Whole peat dome transect based WTD data |
| Biophysical   | Fine fuel moisture content    | Red         | No              | New research required                                                       | Collected at different fire degradation forest categories |
| Biophysical   | Peat flammability             | Red         | No              | New research required                                                       | Controlled experiments under different env. conditions |
| Biophysical   | Peat decomposition level       | Red         | No              | New research required                                                       | Field & lab measurement |
| Biophysical   | Surface fuel flammability     | Red         | No              | New research required                                                       | Controlled experiments under different env. conditions |
| Biophysical   | Peat decomposition level       | Red         | No              | New research required                                                       | Collected at different fire degradation forest categories |
| Biophysical   | Peat moisture content         | Red         | No              | New research required                                                       | Collected temporally and spatially |

*Secondary data*
4. Conclusions
This study describes the need, progress and next steps for Indonesia to have a functioning PFDRS for its tropical peatlands, that is able to improve prediction and targeted fire management. This study has highlighted the wide range of data types that are required for this PFDRS, and provided from multiple disciplines and numerous institutions. It has equally been shown that much progress has been made in both collecting these data, and collaboration among the institutes that contribute data into the model. Some key aspects of data are however still absent. These are most notably those which require on-the-ground biophysical data collection. We show which data collection activities are required in the future, and what methods might be used. We also describe how working with a FDRS modeller will be a key next step for correctly weighting the relational importance of each input variable. Finally, we have highlighted the importance of the continuation of the PFDRS Stakeholder Engagement Network to keep momentum and knowledge exchange moving forwards in this important research space.

Acknowledgements
The authors thank the Australian Centre for International Agriculture Research (ACIAR) for funding this work through the Gambut Kita Project (FST-2016-144). We also thank Andrew Sullivan for his guidance and teaching in this space.

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