Malaysia

A technology-based approach to predicting fire risk in tropical peatland and developing a transboundary haze alert system

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Focus

Transboundary haze is a form of air pollution that affects tropical, ASEAN countries (Association of Southeast Asian Nations), particularly Indonesia, Malaysia, Singapore and Thailand. These countries are located in a region that has large areas of peatland, an important ecosystem and home to millions of people, plants and animals. However, in hot, dry weather the peatland combusts easily and the smoke and dust particles from fires can drift across country boundaries and cause transboundary haze.

Regional air quality in Southeast Asia is seasonally affected by the phenomenon, which is often the result of forest fires from traditional 'slash-and-burn' agricultural methods. In 2015, the fire and haze situation in Malaysia cost twice as much as the reconstruction after the 2014 tsunami (USD 16 billion). Transboundary haze does not only affect the economy; it has also led to health risks from exposure to air pollution such as respiratory and cardiovascular diseases (Yeo, *et al.*, 2014; Tan, *et al.*, 2000).

An integrated, technology-based approach to peatland forest management would allow for more accurate fire risk prediction and thus ameliorate the impact of transboundary haze. However, there are several challenges in ASEAN:

1. A of lack robust air quality monitoring infrastructure to enable reliable data collection at a regional level;
2. The locations of health events are often geographically distant from the nearest air pollution monitoring sites;
3. Some government agencies are reluctant to release air pollution data.

The Canadian Fire Weather Index (FWI) is one source of data used in fire prediction. It is the basis for the Fire Danger Rating System (FDRS), used to predict fires across Southeast Asia. However, the FDRS does not incorporate soil observation parameters such as groundwater level, which is particularly significant in tropical areas with a higher likelihood of rainy days. This limitation highlights the need for a model that integrates groundwater level and other soil parameters into the existing FWI.

Internet of Things (IoT) system

One approach is to monitor the moisture content of the peatland using an IoT system. This system incorporates sensors which can measure soil moisture (among other things) and then model the evaporation rate from the soil using various factors such as temperature, rainfall and humidity. Historical data from the sensors can be used to train the model to predict the evaporation rate in real time and provide early warning of potential fire risks.

Multi-layer neural network

Using data from the IoT system and existing indices (FDRS and FWI), researchers used a multi-layer neural network (a type of machine learning process) to predict localized fire risk with increased precision. To compare levels of accuracy, researchers used two neural networks: one that used four input factors utilized by the current FWI (temperature, humidity, wind speed and rainfall data); and another that used five further input factors, incorporating soil temperature and moisture content, solar radiation, groundwater level and air pressure.

This case study, therefore, focuses on a new approach for calculating moisture levels in tropical peatland. It deploys an IoT system at Raja Musa Forest Reserve (RMFR) as a proof-of-concept for technology-based peatland management and uses a supervised multi-layer neural network to predict the Fire Weather Index (FWI) of the peatland forests.

Method

IoT system for peatland forest management

Raja Musa Forest Reserve (RMFR) in Selangor, Malaysia, presented an ideal location for the study with its vast distribution of peatland, shown in dark brown (Figure 1).

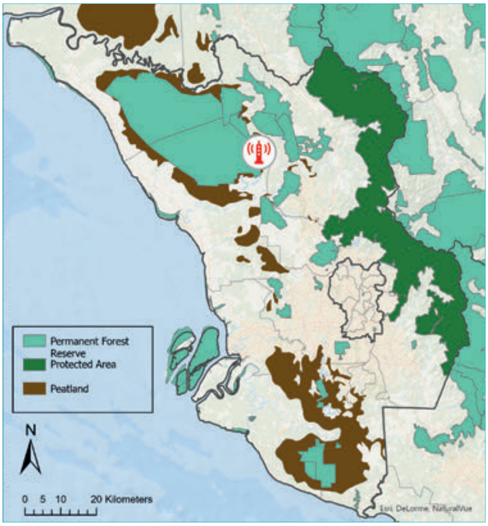

Figure 1: Peatland distribution in Raja Musa Forest Reserve (RMFR) and the location of the IoT system (3°27′58″ N, 101°26′31″ E)

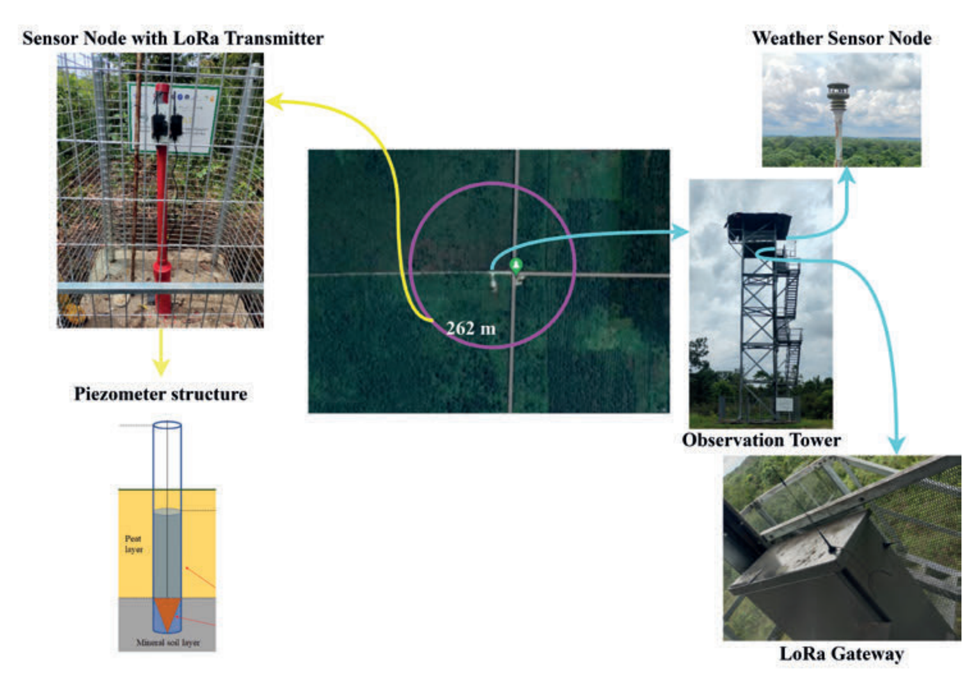

Figure 2: Deployment structure of the IoT system. Piezometer measures groundwater level. LoRa gateway allows data to be sent wirelessly to researchers

An IoT system was deployed to facilitate data monitoring and collection (Figure 2). The system's layout and structure were designed to enable efficient and comprehensive monitoring of relevant parameters and thus provide real-time data. Temperature, humidity and rainfall data, provided by the Malaysian Meteorological Department (METMalaysia), were obtained from a weather station situated approximately eight kilometres from the IoT system. The same parameters were also measured by sensors at the IoT site. A LoRa (long-range) transmitter allowed data to be sent wirelessly to researchers.

Results

Figure 3 shows the data from the nine parameters monitored by the IoT system in RMFR. The meteorological parameters were atmospheric temperature, atmospheric humidity, wind speed, rainfall, air pressure and solar radiation. The peatland parameters were groundwater level, soil temperature and soil humidity. Each subgraph's abscissa (horizontal axis) represents the parameter's value, while the ordinate (vertical axis) represents the number of times that value was measured. The number of samples for all nine meteorological and peatland (ground) parameters was the same (i.e. 47,306 samples).

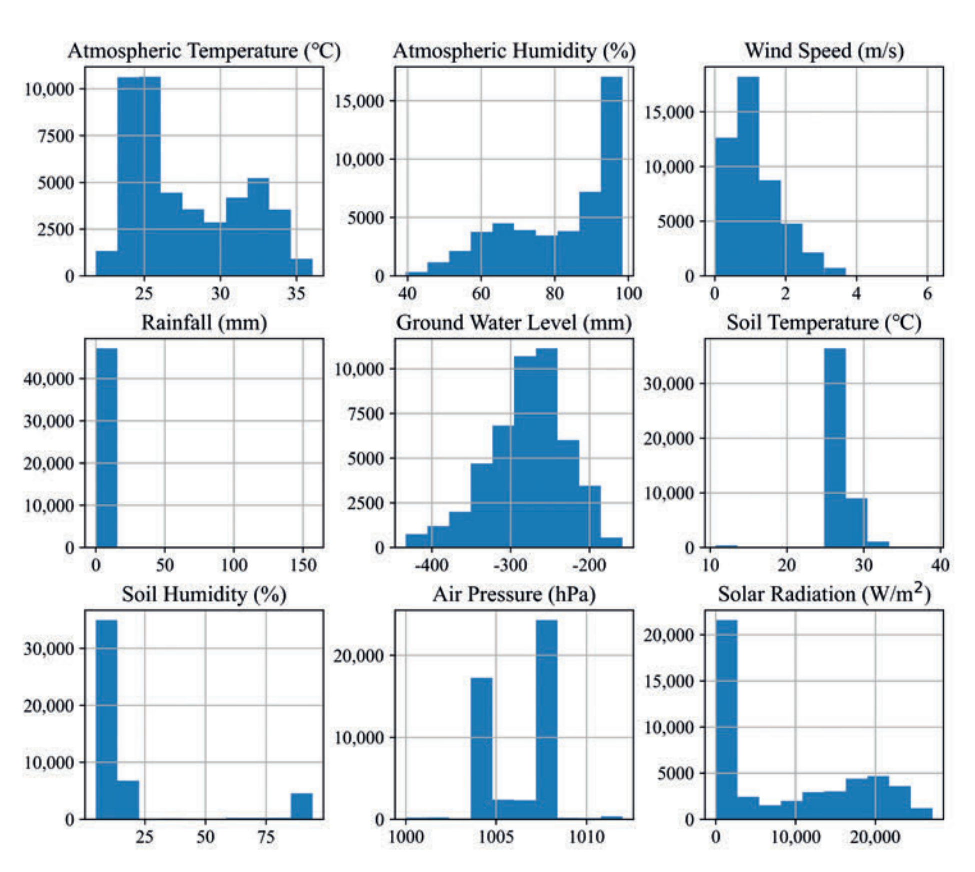

Figure 3: Peatland data measured by IoT system from ground and weather sensors

Neural network for predicting FWI

Neural networks have strong self-learning, self-organizing and adaptive capabilities (Chen, *et al.*, 2021). This has advantages in processing random or unclear information (Ahmadi, *et al.*, 2022). First proposed by Van Wagner (1987), the Canadian Fire Weather Index (FWI) uses four parameters to predict fires (temperature, humidity, wind speed and rainfall). In this study the same parameters were used to generate a four-input neural network (Figure 4).

Multi-layer neural networks calculate outputs by weighting inputs from the input layer (calculating the connections between temperature, humidity, wind speed and rainfall) and applying a series of activation functions to calculate output. Activation

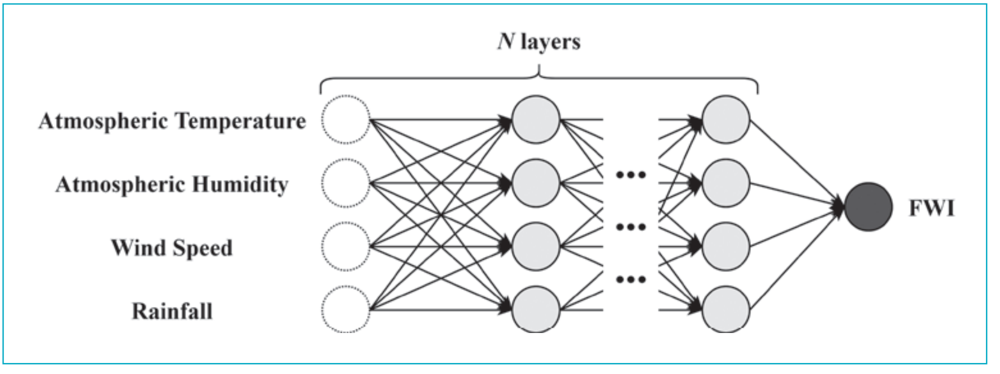

Figure 4: Four-input, (N-layer) neural network for predicting the Fire Weather Index (FWI) (where N is a neuron or node)

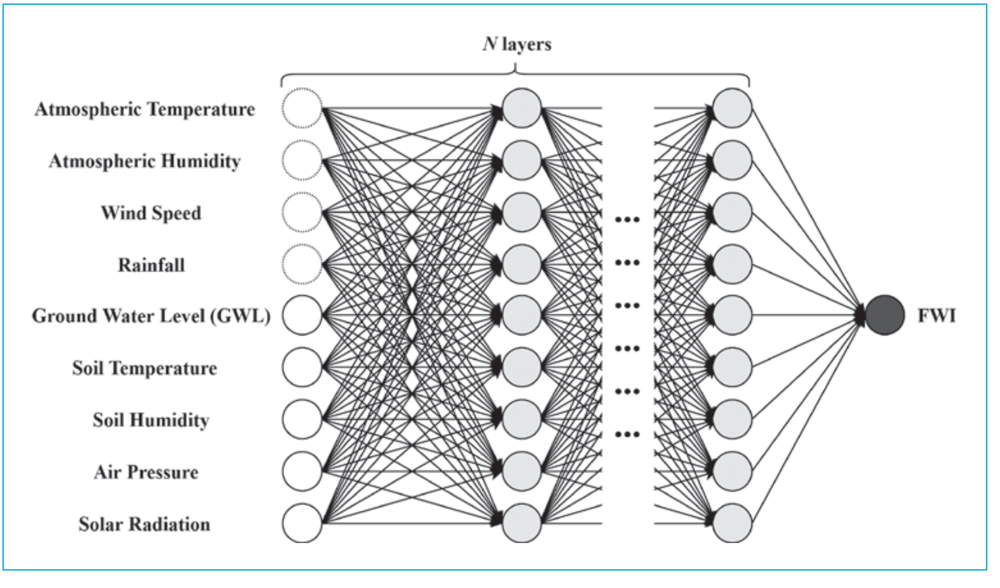

Figure 5: A multi-layer neural network structure with nine-input parameters

functions help the neural network to use important information while suppressing irrelevant data points. This process (input–>activation–>output) is repeated multiple times to minimize error and eventually produce a single output value – in this case, the FWI (Fire Weather Index).

However, atmospheric pressure, solar radiation and most importantly, soil parameters (groundwater level, soil temperature and soil humidity) need to be considered to accurately predict peatland fires in tropical areas. Therefore, this study employed a second multi-layer neural network that considered five further potential factors (nine in total) to predict the occurrence of peatland fires in Malaysia (Figure 5).

Results

The study found that while the existing Fire Weather Index (FWI) model calculated fire risk based on meteorological parameters such as temperature, humidity, rainfall and wind speed, it was indeed beneficial to consider additional parameters for a more comprehensive assessment of fire risk in peatlands.

1. The additional factors (solar radiation, soil temperature, soil humidity, pressure and groundwater level) can provide valuable insights into fire risk assessments in peatlands, as follows:
2. Solar radiation represents the amount of energy received from the sun and influences the drying potential of vegetation and fuel (vegetation available to a fire) moisture content. Higher solar radiation levels contribute to increased evaporation rates and can accelerate the drying of peatland vegetation.
3. Soil temperature plays a crucial role in determining fuel moisture content and the ignition potential of peatlands. Elevated soil temperatures can lead to drier conditions and more favourable conditions for ignition and fire spread.
4. Soil humidity, specifically moisture content in the upper layers of the soil, is a critical parameter for assessing fire risk. Dry soil conditions contribute to reduced moisture availability for vegetation, increasing the potential for fire ignition and spread.
5. Atmospheric pressure affects weather patterns and airflow, which can impact fire behaviour and fire spread. Changes in atmospheric pressure can influence wind patterns, the availability of oxygen for combustion and the overall stability of the atmosphere.

6. Groundwater level is a critical parameter for understanding the moisture conditions in peatlands. High groundwater levels indicate a higher availability of water for fire suppression and can serve as a natural firebreak. Monitoring groundwater levels helps identify areas with a lower fire risk due to the presence of sufficient moisture. Additionally, changes in groundwater level can affect peatland hydrology and contribute to variations in fire behaviour.

Lessons learned

1. The proposed method for predicting peatland forest fires in Malaysia demonstrates distinct advantages compared to the existing approaches (Hayasaka, *et al.*, 2022; Fitriany, *et al.*, 2021). It exhibits real-time capability and automation, setting it apart from traditional methods (Fernandes, 2019; Varela, *et al.*, 2019) that are reliant on manual data collection and analysis.

2. The utilization of machine learning algorithms (multi-layer neural networks) meant the data collected could be automatically processed and analysed in real time. This enabled the efficient and timely prediction of the Fire Weather Index (FWI).

3. The accuracy and reliability of the predictions were validated by comparing them with the actual values published by METMalaysia during the corresponding period.

4. The traditional 'slash-and-burn' land clearance method practiced by smallholder farmers, comes from the misconception that the burning process increases soil fertility. However, research shows that burning causes the greatest nutrient loss of any forest disturbance. Thus, community- and technology-based human activity monitoring can be included in the proposed IoT system. For example, high-resolution vision machines can be installed to monitor activities in peatland forests. This can be used in conjunction with social interventions, such as encouraging local involvement in fire prevention and control, to enhance communal responsibility.

5. The ASEAN Peatland Management Strategy (APMS) has reported that the high level of organic carbon in peatlands makes them significant carbon stores. Peatlands of the region are thought to store up to 5% of all carbon stored on the world's land surface. The clearance, drainage and burning of peatland is now leading to significant carbon emissions which are considered to have global significance. Hence, there is a need to study peatland soil degradation and its relationship to CO_2 emissions. Gas sensors can be installed in the IoT system and greenhouse gas emissions, such as carbon monoxide and methane, can be monitored more regularly.

Conclusion

Forest fires and transboundary haze have a devastating impact on local communities and people across the region. This case study presents a promising approach to predicting and preventing peatland forest fires using IoT technology and machine learning (Hayasaka, *et al.*, 2020), offering real-time capability and automation. It highlights the importance of considering a wide range of parameters, including soil conditions, in fire risk assessment. Given the transboundary nature of the issue, the research findings are particularly valuable for forest management and fire prevention authorities in the ASEAN region. In fact, since the start of this project, IoT systems have been replicated in peatland forests in Badas, Brunei and Jambi, Indonesia.

Therefore, this case study contains important guidance, significant for the future of fire prevention, and which contributes to the growing body of knowledge on leveraging technology to address environmental challenges.

Further information on this research is available at:

Sali, A., Mohd Ali, A., Ali, B.M., Syed Ahmad Abdul Rahman, S.M., Liew, J.T., Saleh, N.L., Nuruddin, A.A., Mohd Razali, S., Nsaif, I.G., Ramli, N., et al. Peatlands monitoring in Malaysia with IoT Systems: Preliminary experimental results. In Computational Intelligence in Information Systems: Proceedings of the Computational Intelligence in Information Systems Conference (CIIS 2020); Springer International Publishing: Berlin/Heidelberg, Germany, 2021 (233–242).

Bibliography

Ahmadi, M., Soofiabadi, M., Nikpour, M., Naderi, H., Abdullah, L., Arandian, B. Developing a Deep Neural Network with Fuzzy Wavelets and Integrating an Inline PSO to Predict Energy Consumption Patterns in Urban Buildings. Mathematics 2022;10 (1270).

Chen, Q., Song, Y., Zhao, J. Short-term traffic flow prediction based on improved wavelet neural network. Neural Comput. Appl. 2021;33 (8181–8190).

Fernandes, P.M. Variation in the Canadian Fire Weather Index Thresholds for Increasingly Larger Fires in Portugal. Forests 2019;10 (838).

Fitriany, A.A., Flatau, P.J., Khoirunurrofik, K., Riama, N.F. Assessment on the Use of Meteorological and Social Media Information for Forest Fire Detection and Prediction in Riau, Indonesia. *Sustainability* 2021;13 (11188).

Hayasaka, H., Usup, A., Naito, D. New Approach Evaluating Peatland Fires in Indonesian Factors. *Remote Sens*. 2020;12 (2055).

Tan, W.C., Qiu, D., Liam, B.L., Ng, T.P., Lee, S.H., van Eeden, S.F., D'Yachkova, Y., Hogg, J.C. The Human Bone Marrow Response to Acute Air Pollution Caused by Forest Fires. Am. J. Respir. Crit. Care Med. 2000;161:1213–1217. doi:10.1164/ajrccm.161.4.9904084.

Van Wagner, C.E., and Petawawa, F. Development and Structure of the Canadian Forest Fireweather Index System. In Forestry Technical Report, Canadian Forestry Service: Victoria, BC, Canada, 1987; 35 (35).

Varela, V., Vlachogiannis, D., Sfetsos, A., Karozis, S., Politi, N., Giroud, F. Projection of Forest Fire Danger due to Climate Change in the French Mediterranean Region. *Sustainability* 2019;11 (4284).

Yeo B., Liew C.F., Oon H.H. Clinical Experience and Impact of a Community-Led Volunteer Atmospheric Haze Clinic in Singapore. Southeast Asian J. Trop. Med. Public Health. 2014;45 (1448–1453).