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Open data application to evaluate exposure of wildfire to water resources: A case study in Johor, Malaysia

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Abstract: Climate change impacts wildfire events as well as water availability. Exposure of water resources to wildfire can reduce water quality supplied to humans and resulting health problems. On the other hand, water resources such as rivers and ponds are essential in wildfire firefighting. This paper intended to assess spatially the exposure of water resources to wildfire. A case study in Johor, Malaysia is utilised to asses and determine locations of water bodies in an area which are vulnerable to wildfire. Post wildfire runoff water can contaminate water resources. Fire data collected by MODIS from 2000–2020 are used to create a hotspot map. Water resources and waterbody data originated from Department of Surveying and Mapping Malaysia used to identify the stream and dams that are exposed to wildfire. 5 class exposure level has been set to show the degree of closeness of water resources to wildfire hotspot area. Using the spatial analysis method, low to high level of potential wildfire-water exposures were able to be locate. Analysis shows, 7% of Johor's water sources is exposed to medium levels of wildfire, while just 1% is exposed to the highest levels. The majority of the streams have very low levels of exposure. In addition, the wildfire-water exposure map aids in first respondent preparedness and planning.

Keywords: Water resources; Hotspots; Wildfire; Exposure; Spatial analysis.

INTRODUCTION

Southeast Asia is one of the world's most disaster-prone regions, with multiple natural disasters such as floods, earthquakes, and heatwaves that triggers wildfire, occurring every year. The severity of wildfires varies from year to year, especially in the southern ASEAN region which are exposed to dry season apart from the monsoon. The haze crisis that hit Asian countries such as Indonesia, Malaysia, Singapore, and Thailand in 2015 and 2019 was caused by forest fires in Indonesia that destroyed 857,756 hectares of peat and mineral soil in 2019 and 2.6 million hectares in 2015 fire episode. Similarly, in Malaysia, socioeconomic causes deforestation, and global climate are variables that contribute to wildfires. Several research on human health have been conducted to assess the impact of contaminated air caused by wildfires, and it has been discovered that wildfires have major consequences on human health, particularly those connected to respiratory diseases (Adam et al., 2021; Chomanee et al., 2020; Jaafar et al., 2021; Koplitz et al., 2016).

Similar to how wildfires harmed air quality, they had an immediate and long-term influence on water quality. Robinne (2016) created the first global estimate of wildfire hazards to water security in the form of a spatially explicit index. The study shows that water security in many world regions is potentially vulnerable to wildfire regardless of socio-economic status (Robinne et al., 2016). The most recent research by Pennino (2022) also found a significant increase in the amount of suspended sediments in streams after a wildfire event (Pennino et al., 2022). Increasing sediments in water sources decrease the lifetime of dams. Changes in water quality may be manifest under different runoff conditions. Effects tend to be greatest soon after a fire; a "first flush" storm can significantly increase dissolved organic carbon (DOC), turbidity, nitrate, and other constituents. Substantially more sediment can be expected to degrade water quality and reduce water storage capacity in reservoirs. (Murphy et al., 2018). Rust's conducted analysis of nutrients in the post-wildfire water sources which shows significant increases in nutrient flux (different forms of nitrogen and phosphorus), major-ion flux, and metal concentrations. Changes in stream water quality within the first five years after the fire are most commonly observe. Dissolved constituents of ions and metals tended to decrease in concentration five years after the fire, whereas particulate matter concentration continued to increase. (Rust et al., 2018). Increasing trends in wildfire severity and elevated Nitrogen deposition demonstrate the potential for substantial post-wildfire changes in ecosystem Nitrogen retention and have implications for nutrient export to downstream waters (Rhoades et al., 2018).

A study of water resources exposure to wildfire is needed in conjunction to emerging increasing of wildfire recorded in Southeast Asia, especially in Malaysia. Malaysia is the second largest source of global palm oil after Indonesia, with a total palm oil plantation area of 5.865 million hectares, 13 percent of which is planted on peat land (Hashim et al., 2018). The exposure of water supplies to wildfire is becoming a concern, as Malaysia relies heavily on surface water for supply and the increasing trends of wildfire in recent years.

Malaysia relies on its annual rainfall as its primary water source. Malaysia's 3rd biennial report to UNFCCC states that Malaysia receives about 973,000 m^3 of water from rain annually. From this, the total surface runoff is estimated to be

496,000 m^3 per year (Ministry of Environment and Water, 2020). As the third most populated state in Malaysia, Johor's water demand projection is expected to increase by 17% in 2030 compared to 2020, due to population expansion and urbanization, putting water resources under stress Statistic of water supplied in 2019 shows a 7.5% increment of water supply due to increasing water usage in Johor compared to 2018. (Department of Statistic Malaysia, 2021). The state government is looking for new water sources as an alternative to the existing water storage reservoirs in the state. The state government carried out various studies and several activities to find the potential of new water resources in the state, such as groundwater (Ranhill Utilities Berhad, 2021). Currently, limited and polluted surface water supplies need exorbitant treatment expenditures, which may be aggravated by wildfire pollution. In addition to being Malaysia's third largest state with palm oil plantations, the state of Johor is also endangered by wildfires, particularly in the peatland area. Johor has the second highest reported wildfire activity in peninsular Malaysia after Selangor state. The number of wildfires in Johor state increased each year from 2017–2019. Receiving this post-fire runoff would be a problem for water treatment plants (United States Environmental Protection Agency, 2019).

The assessment of wildfire risk is critical for fire management. It can be examined at several spatial and temporal levels, including global and local, as well as short-term and long-term fire risk estimation. Global scales can help define basic guidelines for fire management at the continental level, whilst local scales are needed for specific fire prevention resources of small locations (Yakubu et al., 2015). This preliminary study on the exposure of water resources to wildfire is vital for local state decision makers and to acquire an overall condition of the watershed that should be analysed for the pollutant content produced by wildfire.

STUDY AREA

This study focuses on water resources and wildfire in Johor as a case-study area shown in Figure 1. Johor is Peninsular (West) Malaysia's southernmost state, neighbouring to Singapore and Indonesia. Its 400-kilometer coastline encircles the South China Sea and the Malacca Strait. The area of study located approximately on 1° 59′ 27″ N and 103° 28′ 58″ E with a total area of 19,166 km^2. The Maximum altitude is 1276 m above sea level.

The region's weather varies with altitude and can be divided into two distinct seasons, dry and rainy seasons. The dry season is from March to September, whereas the rainy season is from November to February. The annual temperature varies significantly across the area, ranging from 24 to 33 degrees Celsius with mild and humid weather. There are four meteorological stations in Johor that continuously track the weather and offer information for weather forecasting (Figure 1). The stations are Batu Pahat, Kluang, Mersing, and Senai (MetMalaysia, 2020).

Johor's population in 2020 was 3773500, with 99.9% of residents having treated tap water. The total treated daily water consumption for domestic purposes in 2019 was 835,000 m^3, while daily treated water use for commercial and industrial purposes was 599,000 m^3. Concerns about the availability of water sources are growing due to the trend of rising water usage, and outside factors like contamination from wildfires can put pressure on the supply. In addition, treated water are also used as supply for fire hydrants. In 2019, there were 8,354 fire incidents reported, which is 3426 more than in 2018.

DATA SOURCES

Data regarding the fire hotspot were obtained from NASA's Fire Information for Resource Management System (FIRMS), (Giglio et al., 2020), which distributes near real-time fire products from Moderate Resolution Imaging Spectroradiometer (MODIS) from the Terra and Aqua platforms with a spatial resolution of 1 km. Each position of a MODIS-identified active fire represents the centre of a 1 km × 1 km pixel labelled by the algorithm as containing one or more fires inside the pixel. FIRMS MODIS data has been used to evaluate the spatial and temporal pattern of Mediterranean wildfire (Levin and Heimowitz, 2012) and forest fire hotspot its relationship with climatic variables in Jharkhand, India (Kumari and Pandey, 2020). Only fire pixels with a confidence higher than 80% for the period from December 2000 to October 2020 were considered for further analysis because, in some instances, the product underestimates fire occurrence (Milanović et al., 2021).

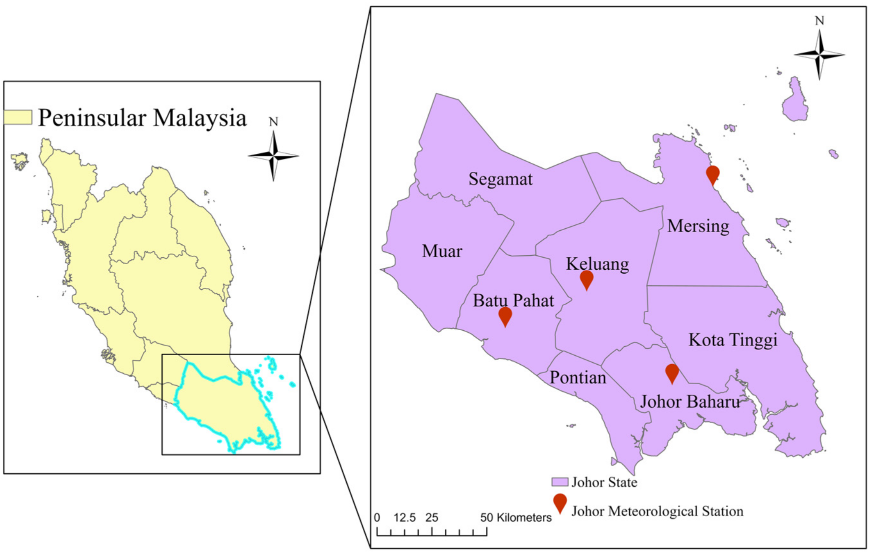

Fig. 1. Descriptions of study area.

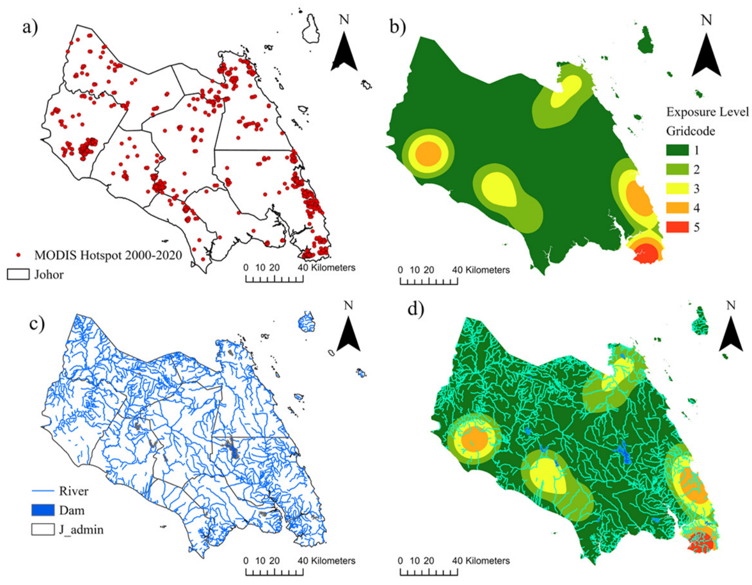

Fig. 2. a) Modis hotspot 2000–2020, b) hotspot heatmap, c) river and inland water body, d) overlayed map.

The layer of river stream and inland water body was downloaded from Stanford Digital Repository website. This polygon shapefile represents areas of inland water and river in Malaysia. The Global Map Malaysia version 2 is extracted from the existing topographic map of scale 1:25000. Global Map data were developed under the cooperation of National Geospatial Information Authorities (NGIAs) of respective countries and regions. Global Map Data of Malaysia developed by Department of Survey and Mapping Malaysia with consistent specifications by NGIAs of respective countries and regions for basic geospatial information of their respective coverage by using geospatial information owned by them (International Steering Committee for Global Mapping and Malaysia. Jabatan Ukur dan Pemetaan, 2013). Both data set are masked to the Johor administration boundary.

DATA PROCESSING

The ArcMap programme is used to handle and analyse data. The kernel density function was used to convert a fire hotspot vector point (Figure 2a) to a raster hotspot density. This tool computes a magnitude-per-unit area from point characteristics by fitting a smoothly tapered surface to each point using a kernel function. To produce a generalised result of the hotspot region, the cell size was set to 100 metres GRID and the search radius was set to 20 kilometres. The term "exposure level" in Figure 2b refers to how near the water stream and body are to the wildfire hotspot region. The exposure level was classified using natural break classification methods based on natural grading inherent in the data. The exposure category identifies the number of wildfire incidents that have been seen there between 2001 and 2020 (Table 1). To identify streams and bodies with high exposure to wildfire, the layer of water streams and bodies (Figure 2c) was superimposed on top of the heat map (Figure 2d).

RESULTS AND DISCUSSION

From the hotspot density analysis, the exposure level of the water stream and inland water body is classified by natural breaks (‘Jenks’) and is represented in Figure 2(b) via 5 classes. This classification method generates classes based on natural groupings of pixel values (Ghorbanzadeh et al., 2019). This method is used so that exposure levels can be compared within a localised study area, in this case, the state of Johor. For the Johor state, very low-level exposure indicates that the features are in an area with 0 to 5 wildfire incidents between 2000 and 2020. That means wildfire events rarely occur. Low level exposure represents a region that saw 6–10 wildfire episodes, medium level exposure 11–18 wildfire events, high level exposure 19–29 wildfire events, and extremely high exposure 30–45 wildfire events. In this investigation, we discovered that most water streams have relatively low exposure to wildfires, which is categorised as level 1 exposure. Only 1% of the streams and water bodies are severely exposed to wildfire at level 5, as shown in Figure 3. This suggests that between 2000 and 2020, these streams were subjected to 30 to 45 wildfires. Sungai Lepau, Sungai Punggai, and Sungai Pengerang are among the rivers that are especially exposed to wildfires since they are located in peatland areas. Level 5 exposure is concentrated in high peatland areas of Pengerang, as illustrated in Figure 2b. Peat fire occurs every year from 2000 until 2020 in Pengerang. MODIS has found 114 fire hotspots in 2019; 63 of the hotspots are in Pengerang alone. This result can be related to local farming and plantation operations which involve peat land. This data is consistent with observations that Malaysia, Cambodia, Brunei, and Myanmar had the highest percentage of forest fires in Southeast Asia, owing primarily to slash and burn agriculture and timber exploitation (Vadrevu et al., 2019). Furthermore, peat fires are extremely hard to put out and take a very long time to be fully diminished, and are aggravated by hot weather, which caused a lack of water in the ditches around the area and

Table 1. Exposure level classification.

Classification	Number of wildfire events between 2001–2020
Very low	0–5
low	6–10
medium	11–18
High	19–29
Very High	30–45

also limited personnel and equipment of the firefighters (Othman et al., 2019). The increasing concerns on water resources in Pengerang District also due to the Refinery and Petrochemical Integrated Development (RAPID) project, The RAPID Pengerang project refinery is designed to produce gasoline and diesel that meets Euro 4 and Euro 5 fuel specifications. It also serves as a source of feedstock for the petrochemical complex, which produces highly specialised chemicals. This project has changed forest and plantation areas into urban areas, which can affect environment, ecology, and hydrological process conditions in the long term (Che Man and Salihin, 2018).

Figure 4 shows, waterbody such as Machap dam, Lebam dam, and Labong dam are exposed to wildfire at level 3. This area experienced 11 to 18 times of wildfire events from 2000–2020. Machap Dam is located in Simpang Renggam, Johor, Malaysia. This water supply dam supplies drinking water to residents around Simpang Renggam, Kluang, Pontian, and others. This dam is included in Rengam district. Semberong Lake, was exposed to 5 to 10 wildfires from 2000–2020, making it a second level exposure. A study of water quality and heavy metal content in Semberong Lake water was conducted from April until August 2015. The results from the study found that the water salinity, conductivity, biochemical oxygen demand (BOD), total suspended solids (TSS), and nitrate level fall under Class I based on the Interim National Water Quality Standard of Malaysia (INWQS). The pH, dissolvable oxygen (DO), and turbidity lie within Class IIA. The values of chemical oxygen in demand (COD) and ammonium were classified under Class III and total phosphate has been detected under Class IV. (Mohd-Asharuddin et al., 2016). Although there is no solid evidence on the cause of high phosphorus and ammonia in Semberong Lake, wildfire often causes increases in nitrate and phosphate content in water sources (Writer et al., 2014). Similar results have been found in the peatland shallow groundwater quality in northern Alberta Canada after prescribed burn (Orlova et al., 2020). Thus, an analysis on the sources of phosphorus and nitrate in Semberong lake can be conducted, to find if its related to wildfire or not. Table 2 shows the exposure of other waterbodies for Johor state.

The results of this study are quite generalised since analysing a large area, such as the whole state, would impose some restrictions on data processing and visualization. In this study, the search radius set for the hotspot kernel density is 20 km. This parameter will affect the calculation of density by dividing the number of points into a larger area. If the search radius is too small, the high-density area will increase and divert attention from the hotspot. This approach can be used for study area selection, and a detailed study can be focused on the high-exposure-risk areas, such as Machap and Bandar Penawar. Wildfire severity, such as burned area and erosion rate, can be exploited in the next level of study to see the impact on water resources.

Table 2. Johor dam exposure level to wildfire.

No	Water body	District	Exposure level
1	Machap dam	Simpang Renggam, Kluang	3
2	Labong dam	Endau, Mersing	3
3	Lebam dan	Bandar Penawar,KotaTinggi	3
4	Semberong dam	Ayer Itam, Batu Pahat	2
5	Sultan Iskandar reservoir	Johor Bharu	1
6	Segamat (Bekok) dam	Segamat	1
7	Linggiu	Kota Tinggi	1
8	Tasik Berlian	Batu Pahat	1
9	Kolam Air Singapura	Johor Bharu	1

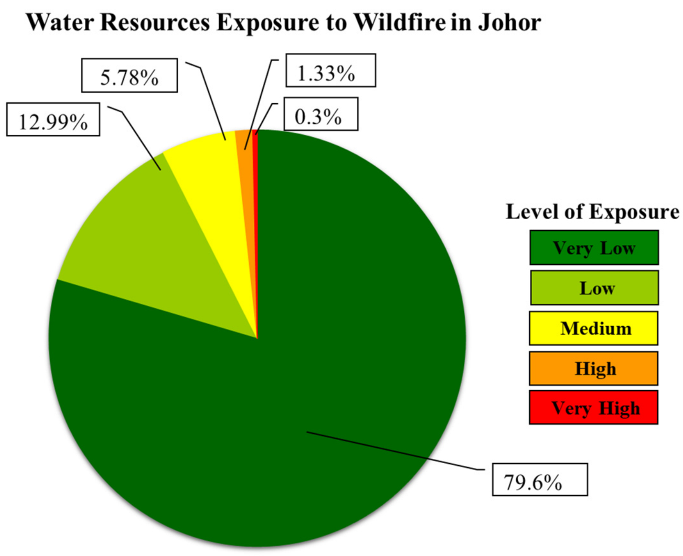

Fig. 3. Level of water resources exposed to wildfire in Johor.

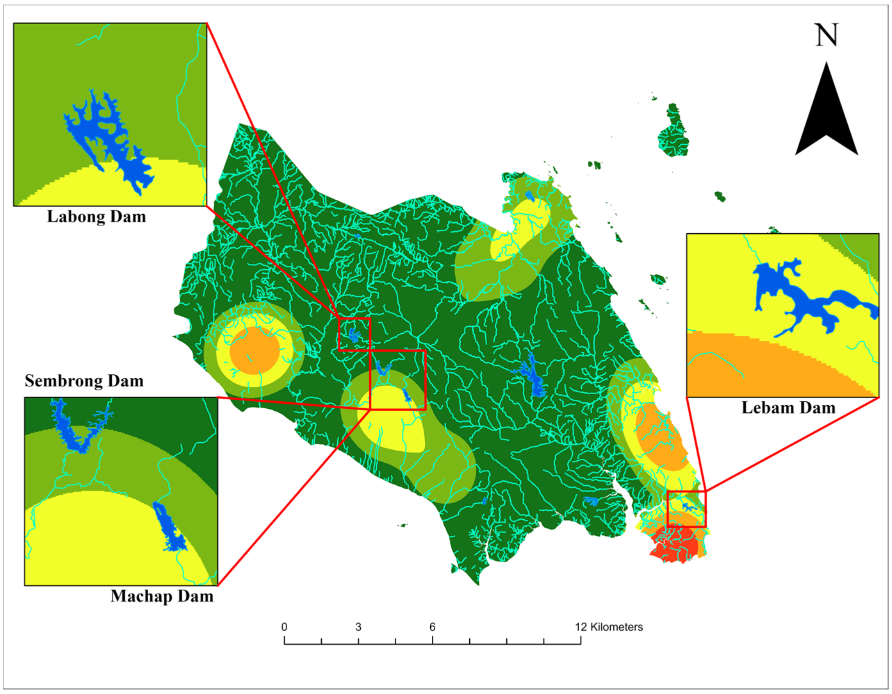

Fig. 4. Dams at 2nd & 3rd level of exposure.

According to a study of wildfire exposure to water resources, conducted on a global basis, tropical wet forests had the highest exposure indices overall. In contrast, intermediate scores tended to be concentrated in a few mountain ranges, boreal forests, and tropical dry forests and shrublands. The tundra, temperate woods, and temperate prairies had the lowest exposure indices. (Robinne et al., 2016). Based on these results, finer scale analyses, such as regional and local studies, are more useful, particularly in peninsular Malaysia. Malaysia is a country with tropical forests and a significant area of peat land. Local study on the impact of exposure to wildfire, should be emphasized because the governance of water resources in each state in Malaysia is managed by a separate identity. Johor was used as a case study region because it has the highest water bodies on peat soil area (1906 hectares), followed by Pahang (116 hectares) and Selangor (1729 hectares) (Davies et al., 2010).

Machap dam and Lebam dam have been at critical levels due to low rainfall and heatwave phenomena in 2019. At that time, the level at these dams has been below a critical level, which has prompted local officials to urge residents to use water sparingly. (Ranhill Holdings Berhad, 2020). The scenario will get worse if wildfires occur frequently close to the dam or along the stream that feeds it because of the increased pollution and sedimentation of the dam's water supply. Furthermore, harmful material may be present in the contaminants due to pyrolysis process during wildfire.

Although Sultan Iskandar Reservoir is exposed to a low level of wildfire, this major reservoir supplying water to some 600,000 households in the state is at risk of contamination due to illegal farming around it. Layang dam draws water from this reservoir, is currently surrounded by many illegal farms and plantations. Farming and plantation have been identified as the major caused of wildfire in Southeast Asia country, especially in Malaysia. Slash and burn techniques used to clear the land and ashes from the burnt trees help farmers by providing nutrients for the soil (Juárez-Orozco et al., 2017).

CONCLUSION

Wildfire is often associated with air pollution and its effects on human health. Not only that, there are also some studies that prove that wildfire affects the quality of water resources, which also can affect human health. However, risk assessment involving water sources that are exposed to wildfires has not been studied much yet. Therefore, this study is one of the initial steps to identify water sources that are vulnerable to wildfires. Since the state of Johor is among the most populous states in Malaysia and growing as economic hub, Johor state has been chosen as the case study area, due to its significant peatland area, wildfire frequency, and increasing demand in water supply. Machap dam, Labong dam, and Lebam dam have been identified as having level 3 wildfire exposure between 2000 and 2020, which means 11 to 18 wildfire events have been recorded between 2000 and 2020.This local scale study is important to identify dams or catchments that are exposed to potential wildfire events. In the Johor case study, Machap dam, Labong dam, and Lebam dam are suggested for water quality exemption prior to wildfire events. On the other hand, the overlay map can also be used to identify the water resources available for firefighting purposes. The layer of road that can be excess and the distance analysis can be done to give information to Fire department for their emergency preparedness. If possible, water depth and pressure also can be included in the next study for emergency responses.

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