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Enhancing fire disaster management: Innovative approaches using physical peatland monitoring data

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ABSTRACT

Background: In Indonesia, the persistent occurrence of forest and land fires highlights the critical importance of early detection in determining the success of mitigation efforts. **Method:** This study explores several key aspects related to peatland wetness and its impact on fire prevention. Firstly, it examines the relationship between rainfall and the humidity and temperature of peatlands. Secondly, the study investigates peatland wetness as an indicator of hotspot emergence. Thirdly, the study evaluates stakeholder perceptions regarding the use of peat wetness monitoring in determining the emergency status of forest and land fire disasters. **Findings:** The study's results indicate that rainfall significantly influences peatland humidity, which in turn reflects the level of peat humidity and temperature. It was also found that peatlands with a Dry-Moderate humidity category can be a reliable indicator of the emergence of fire spots. The consensus among stakeholders is that monitoring peatland humidity is very important for decision-making related to emergency status. Finally, this study proposes a forest and land fire mitigation concept based on peatland humidity. **Conclusion:** This approach aims to reduce the risk of such fires by utilizing monitoring results to enhance preparedness, taking into consideration the current state of peatland wetness. Overall, this research underscores the importance of integrating peatland wetness monitoring into forest and land fire mitigation strategies to improve early detection and reduce the risk of fires. **Novelty/Originality of this study:** A study of forest fires in Indonesia links peatland wetness to fire hotspots, providing a reliable indicator for early fire detection. This is an innovative approach to forest fire prevention.

KEYWORDS: early detection; forest and land fires; hotspots; mitigation; peatland wetness

1. Introduction

Forest and land fires, or what are usually called forest and land fires, are disasters that regularly occur in Indonesia. The research conducted by Field et al. (2016) highlighted that over the past three decades, forest and land fires in Indonesia have become increasingly alarming. Huijnen et al. (2016) identified Sumatra and Kalimantan as regions in Indonesia that significantly contribute to carbon emissions and toxic gases generated from forest and land fire smoke. These fires, categorized as hydrometeorological disasters, frequently affect provinces with vast peatland areas, including Riau, Jambi, and South Sumatra on the island of Sumatra, as well as West Kalimantan, Central Kalimantan, South Kalimantan, and East Kalimantan on the island of Kalimantan. The burning of peat forests during deforestation contributes approximately 15% of global greenhouse gas emissions. As one of the world's

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largest tropical forest nations, Indonesia has been losing 1.13 million hectares of forest annually during the 2009–2013 period—equivalent to clearing three football fields per minute. Although there is positive progress with reduced deforestation rates, the figures remain substantial. This situates deforestation and peatland burning as the leading contributors to greenhouse gas emissions in Indonesia (Austin et al., 2019; Palmer, 2001)..

Karhutla is a disaster that is very easy to occur, but also very difficult to handle if it is late in providing mitigation action. Therefore, a forest and land fires disaster that has spread over a large area will certainly be very detrimental not only materially, but also environmental losses, especially in the destruction of the ecosystem of forestry and plantation areas. Fire smoke generated from peatland fires has various negative impacts on life. Apart from disrupting economic activities, the direct impact of smoke from forest fires in peatlands causes atmospheric pollution (smog) which has a negative impact on people's health. There is a long history of forest fires in Indonesian peatlands, such as in 1997, when a strong El Nino occurred, resulting in dense smoke haze covering an area of up to 4 million km2in Southeast Asia and affects the livelihoods and health of 75 million people in six countries. Apart from that, the haze also causes paralysis of the transportation sector, such as airport closures (Fujii et al., 2014; Lan et al., 2021; Tham et al., 2019).

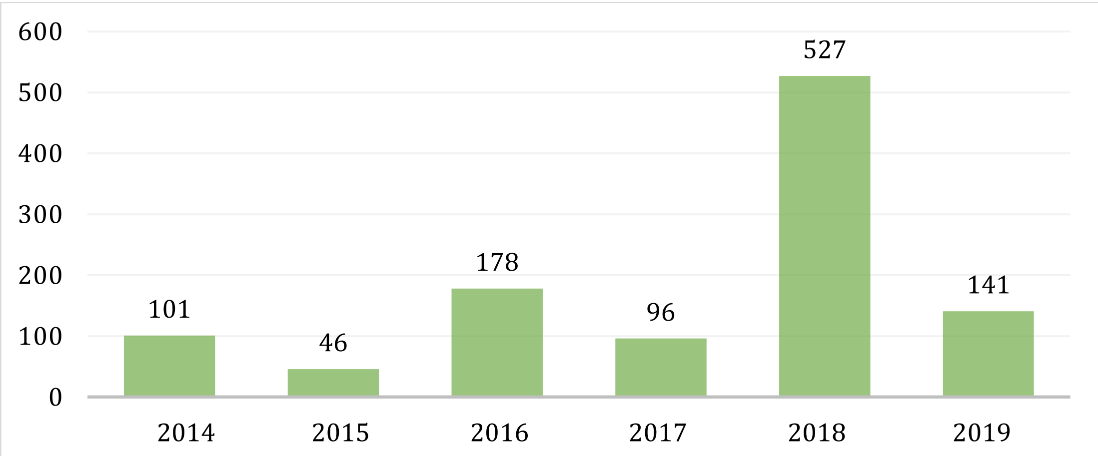


Fig. 1. Number of forest and land fire incidents 2014-2019
(National Disaster Management Agency, 2020)

Referring to the National Disaster Management Agency (BNPB) database as presented in Fig. 1, in the 2014-2019 period at least every year there were around 100 forest and land fire incidents. Even though 2015 and 2017 showed frequency values below 100, this cannot be the only indication to see how severe the impact of fires were in those years. By the Ministry of Environment and Forestry (KLHK), the area of forest and land fires is calculated based on analysis of Landsat 8 OLI/TIRS satellite imagery which is superimposed with hotspot distribution data, as well as fire spot groundcheck reports and extinguishing reports carried out by fire personnel.

In addition to causing material and environmental losses, and even claiming numerous lives, forest and land fires (KARHUTLA) also "contribute" significant amounts of carbon dioxide to the atmosphere at alarming levels. Forest fires are disasters that have various negative impacts on the environment, economy, and society. The Indonesian government reported that the economic losses from forest fires in 2019 amounted to USD 5.2 billion, while in 2015, the figure reached USD 16.1 billion, both representing the periods of the largest forest fires in Indonesia over the past decade (National Disaster Management Agency, 2020, 2020).

The immediate impact felt by communities includes respiratory problems caused by the smoke, which can lead to more severe and acute respiratory disorders. The dense smoke from the fires also limits human mobility, disrupting daily activities and adversely affecting the economic sector. Environmental losses include increased carbon emissions, vegetation damage, and the loss of biodiversity. On a global scale, the effects of forest fires contribute to global warming, reductions in temperature and light intensity, and potential impacts on the El Niño Southern Oscillation (ENSO).

The losses caused by forest and land fires, besides being economically burdensome, are also highly detrimental ecologically. Peatlands damaged by fire require a significant amount of time to recover and regain their ecological functions (Glauber & Gunawan, 2015; Harrison et al., 2009; Purnomo et al., 2017).

One of the provinces in Indonesia that experiences forest fires annually is Riau Province, located on the island of Sumatra. Riau is the province with the largest peatland coverage on Sumatra, spanning up to 2.2 million hectares (CIFOR, 2020). In the example of large forest fires in Riau province, 2289 fire hotspots were detected with a fire area reaching 90,550 hectares during 2019 (Ministry of Environment and Forestry, 2021). In response to forest and land fires which almost always occur every year, the government has always carried out massive handling of forest and land fire disasters in recent years. However, unfortunately, the timeliness of implementing forest and land fire disaster management activities is often considered too late. For example, the Agency for the Assessment and Application of Technology (BPPT), through its Weather Modification Technology, is one of the agencies that is often appointed to provide solutions that are routinely implemented when forest and land fires occur. The function of Weather Modification Technology (TMC) is expected to be able to wet peatlands so that it can help extinguish hotspots. In reality, TMC operations in the field are often hampered by the lack of cloud supply during the peak of the dry season. This happens partly because the implementation of TMC often takes place when forest and land fires have already occurred widely with very high escalation of hotspots. This certainly makes it very difficult for the technology to maximize the growth of clouds into rain. Government intervention in extinguishing fires is often carried out when climatic conditions have reached the peak of the dry season, or in other words when many fires have emerged. Fire fighting activities carried out by land or by air, such as the use of water bombing and the application of Weather Modification Technology, often experience problems because they are carried out during the peak of the dry season. This is a problem, especially if you look at the characteristics of peat which is prone to peat smouldering phenomena, resulting in the detection of hotspots and extinguishing them. The peat fire/peat smouldering phenomenon is a fire in peatlands that can occur below the surface, so the spread of fire is very difficult to detect. It was further explained that peat smouldering is a combustion that occurs in porous fuel which is slow, low temperature, without flame on the surface, and is the most persistent type of combustion phenomenon (Cochrane, 2015; Rein, 2016).

Efforts to extinguish forest fires carried out at the peak of the dry season are often ineffective and inefficient. As previously mentioned, the phenomenon of forest fires in peatlands can occur below the surface through the peat smouldering phenomenon. In peatlands, according to Wilkinson et al. (2018) fires that occur on the surface can easily ignite fires in deeper layers of more than 50 cm. This occurs due to the influence of the wetness level of the peatland. Goldstein et al. (2020) explained that the dryness of peatlands, both at the surface and deeper layers, is very influential in the peat smouldering phenomenon. To see the potential of peat smouldering, there have been several previous studies which emphasize that observing the physical condition of peatlands is important in the forest and land fire disaster mitigation paradigm. The wetness of peatlands is one of the indicators in the concept of forest and land fire disaster mitigation. Peatland wetness, which can be measured from soil moisture, according to Huang & Rein (2017), can be an indication of the level of vulnerability of a peatland to fire. Restuccia et al. (2017) identified that the probability of forest and land fires in peatlands occurring on the surface is influenced by several factors such as soil moisture, mineral content and other chemical conditions. Apart from that, other factors causing fires in peatlands described by Stracher et al. (2015) is the temperature below the surface of peatlands. As an example of the influence of physical factors on peatlands, especially below the surface, can be seen in the research results of Wösten et al. (2008). In their research on peatlands in Indonesia, although they did not theoretically state that subsurface humidity and temperature factors influenced the emergence of hotspots, Wösten et al. (2008) concluded that in dry years groundwater levels fall below the critical threshold of 40 cm, making them prone to fire.

1.1 Disaster mitigation concept

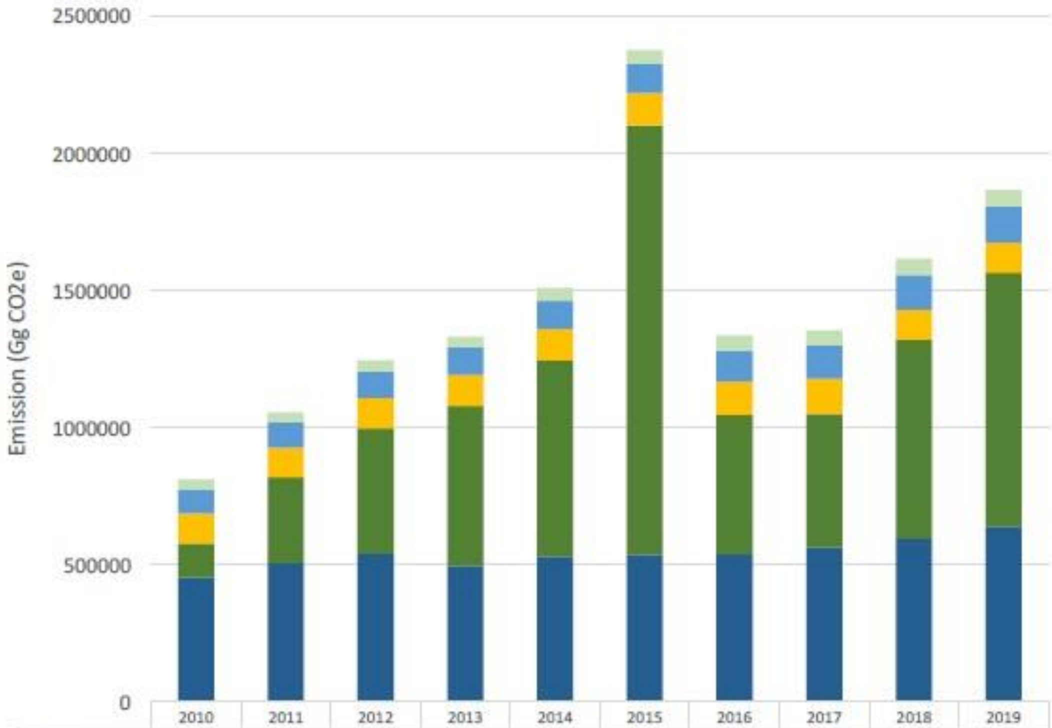
By Carter (2008) disaster mitigation is seen as actions aimed at reducing the impact of disasters that occur in nature, both those that occur naturally and those caused by human activities. This concept tries to explain that through disaster mitigation, the detrimental impacts caused by disasters can be reduced. A similar concept regarding disaster mitigation can also be seen in the Government Regulation of the Republic of Indonesia Number 21 of 2008

Regarding the Implementation of Disaster Management which defines that mitigation is a series of efforts to reduce disaster risk, both through physical development and awareness and increasing capacity to face disaster threats. Secara more specifically, Sandhyavitri et al. (2015) divides the forest and land fire disaster mitigation framework into 4 (four) main steps which include: (1) Understand about fires on peatlands. In this step, studies regarding the characteristics, types and processes of fires on peatlands need to be mastered; (2) Rapid assessment (rapid assessment). This step is based on the conditions of the fire hotspots and the water/canal network system in the field; (3) Early warning (early warning). Early warnings are based on weather and terrain parameters; (4) Emergency response. This step includes action plans carried out by various stakeholders in social, economic, environmental and technological aspects.

Faturahman (2017) explains that the government, society and the private sector have a synergistic relationship in disaster mitigation efforts. In other research, Syaufina (2018) emphasized the need to increase awareness of peatland management, especially in mitigating forest and land fire disasters. Strengthening mitigation can be optimized, one of the ways is through the use of peatland monitoring instruments. The concept of mitigation by taking more into account weather and land parameters as offered in this research can be categorized as a form of mitigation at the early warning stage.

1.2 Forest fires in a sustainable development perspective

The importance of protection and appropriate management in mitigating disasters, including forest fires, is one form of implementing the concept of sustainable development. Sustainability in environmental management in the current era of modernization can be achieved through three approaches, namely: (1) sustainable technological innovation; (2) regulatory innovation (laws) and related programs; and (3) major transformation of sustainable social systems (Burns, 2016). In the report 'Indonesia's Voluntary National Review 2021', forest fires are mentioned as one of the challenges that must receive serious attention in efforts to support sustainable development achievements in Indonesia. It was stated that greenhouse gas emissions resulting from forest fires resulting from Forestry and Other Land Use (FOLU) activities, especially on peatlands, are in fact one of the sectors contributing to the largest carbon emissions on a national scale. As can be seen from Fig. 2, at least 1.5 million Gg CO2e was produced from FOLU and Peat sector emissions in 2015 (Ministry of National Development Planning/BAPPENAS, 2021). Forest fires that occurred that year and other years also contributed to the spike in national emissions.



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
IPPU (all gases)	36,033	35,910	40,078	39,164	47,489	49,297	55,307	55,395	59,262	60,175
Waste	87,670	91,852	95,530	100,514	102,834	106,061	112,352	120,191	127,077	134,119
Agriculture	108,318	107,520	112,058	112,882	112,801	117,160	122,185	127,503	110,055	108,598
FOLU & Peat	124,726	311,440	456,492	582,823	714,707	1,565,500.	507,652	488,517	723,510	924,852
Energy	453,235	507,357	540,419	496,030	531,142	536,306	538,025	562,244	595,665	638,808

Fig. 2. National carbon emissions trends based on producing sectors

The social aspect, there has been a lot of research discussing how sustainable forest management can play an important role in minimizing the potential for forest fires in an area. Floress et al. (2019), for example, concluded that preferences for forest use in the acceptance of forest management practices can pay attention to appropriate plant commodities in order to minimize the potential for ecosystem damage such as that which occurs in forest fires. Land use, land ownership status, and determination of land functions, in many studies, are some of the social indicators that need to be considered in sustainable forest management (Bowditch et al., 2019; Erbaugh, 2019; Mockrin et al., 2020; Uda et al., 2017; Uda et al., 2020; Varkkey, 2013). Other indicators that are vital to pay attention to in managing forests against fires are the strictness of regulations, sanctions, and the importance of applying technology to help see the potential for fires to occur. The need for policy mapping that does not overlap and has strong synergy and coherence in accommodating the interests of several sectors in the utilization of forestry resources, will help in optimizing the prevention and handling of forest fires (Carmenta et al., 2017; Januar et al., 2021; Jefferson et al., 2020; Mourao & Martinho, 2019).

Tacconi et al. (2007) explained that tropical countries face challenges in formulating appropriate policies for sustainable forest fire management. The importance of policy coherence in forest resource management was emphasized by Warsito et al. (2021) as a key factor for achieving resilience against forest and land fires (karhutla). Previous studies have extensively examined that one of the factors influencing forest fires in Indonesia is the suboptimal government intervention in preventive measures.

Schaafsma et al. (2017), in their study aimed at elaborating stakeholder perceptions related to forest fires in Central Kalimantan, revealed that at the prevention stage, local communities still perceive land clearing through burning as a contributing factor to the dynamics of forest fires in Indonesia. Therefore, maximizing government intervention to enhance the role of local communities through various regulations and policies is essential to encourage a paradigm shift toward environmentally friendly land clearing practices, especially in peatland ecosystems.

One of the Indonesian government's initiatives, the establishment of Fire-Free Villages, was described in Carmenta et al. (2017) study as a promising approach, although it requires a strong commitment to consistent law enforcement. Beyond the Fire-Free Village program, strengthening knowledge in peatland management, such as determining appropriate canal blocking locations, adopting alternative land-clearing techniques, and enhancing collaboration between communities and the private sector—often tasked with peatland management responsibilities—should be taken more seriously by the government to support disaster mitigation efforts for forest and land fires (Enrici & Hubacek, 2016; Cadman et al., 2019; Nath et al., 2017; Ward et al., 2021).

2. Methods

This research uses a quantitative approach, where in the analysis it uses qualitative methods. Qualitative methods are used to help understand stakeholder perceptions about how the results of monitoring peatland wetness can describe the potential for forest and land fires that occur in the field. This will help in providing a concept for determining forest and land fire disaster status by utilizing peatland wetness monitoring data, so that forest and land fire disaster management activities in the research area are more effective and efficient.

The research area in this research is Riau Province, Indonesia. Riau Province is located on the central part of Sumatra Island, astronomically located at 100°-104° East Longitude and 2° N - 1°S. Administratively, Riau Province borders directly on the Malacca Strait in the north, Kep Province. Riau in the east, Jambi Province in the south, and West Sumatra and North Sumatra Provinces in the west. Riau Province has a fairly large area of peatland cover, namely 2.2 million hectares (CIFOR, 2020). The research area is one of the provinces in Indonesia that often experiences forest and land fire disasters every year. Peat land cover in Riau Province is widely spread on the eastern coast, such as in the districts of Rokan Hilir, Bengkalis, Siak, Pelalawan, Indragiri Hilir, and parts of Dumai City. However, forest fires that occur every year in Riau Province are the main threat to reducing peat land cover in the region (Jefferson et al., 2020; Tacconi et al., 2019; Uda et al., 2020).

Based on data on the emergence of MODIS terra/aqua satellite hotspots, at least 2,289 forest fires that occurred in 2019 were recorded in Riau Province (KLHK, 2021). Riau's relatively close position to neighboring countries such as Malaysia and Singapore means that forest fire smoke can be transported to these countries via wind (Tham et al., 2019; Wiggins et al., 2018). This makes Riau one of the provinces most highlighted in forest fire disaster mitigation efforts by the Indonesian government. As a form of early detection of forest and land fires, in recent years the Government has made efforts to further strengthen the monitoring aspect of peatlands in Riau Province. One of them is through the use of physical peatland monitoring instruments carried out by BRGM. The conditions in the research area represent the problems raised in this research. More clarity regarding the location of the research area.

This research was carried out for 8 months, from January 2022 to August 2022. The stages carried out included collection, data collection in January-April 2022, data processing in May-June 2022, data analysis and interpretation in July-September 2022 as well as preparing it for this research manuscript.

3. Results and Discussion

Forest and land fires do have complex complexities. The importance of monitoring parameters that can be indicators in determining the potential for forest and land fires will be beneficial for the success of overcoming and controlling forest and land fires. Based on interviews with key informants who are representatives of the main stakeholders related to forest and land fires, the results of physical monitoring of peatlands as discussed in this research can be used to help complete the parameters used in determining the status of forest and land fires disasters, so that they can provide input to improve forest and land fire mitigation. in general. The following are several interview quotes from key informants that support the above findings.

> *"In mitigating forest and land fires, it is important that we know how hydrometeorological parameters behave. So far, what is often observed in determining the response to forest and land fires is still the dominant observation of drought and rainfall dynamics, because that is the most dominant and easiest to observe. However, if direct monitoring of the physical condition of peatlands were increased and the data could be used, it would certainly be very useful." (R, Head of Class I Meteorological Station, Sultan Syarif Kasim II Airport, Riau)*

> *"To mitigate forest and land fires, it is important to use direct observation results as indicators. This will make it easier to formulate the response given to immediately act in mitigating and controlling forest and land fires. For example, weather modification technology activities to maximize the potential for clouds to become rain would be very helpful if implemented before the peak of the dry season. Based on the results of physical monitoring of peatlands, we can identify areas where the land is indicated to be dry so that they can be prioritized as areas for weather modification operations to reduce the potential for forest and land fires. Even with water bombing, monitoring results can also be helped. "So that forest and land fire mitigation can get improvements, especially in terms of selecting execution times and focus of work areas." (BH, Coordinator of Weather Modification Technology Management Laboratory, BRIN)*

> *"If the identification of potential forest and land fires can be assisted by the results of accurate physical monitoring of peatlands, this could be a plus point for mitigation activities. "For us, for example, by identifying which areas are heading towards dry conditions (through physical observation of peatlands), we can develop plans and schemes for deploying ground personnel to patrol these areas more intensively." (EP, Coordinator of Manggala Agni Riau Region)*

Observing the physical condition of peatlands is considered to provide increased mitigation of forest and land fires. Several relevant stakeholders indicated that by observing the dynamics of the physical conditions of peatlands, the response to potential forest and land fires would be helped. This is also related to the more effective mitigation activities will be if assisted by observation data, especially in selecting the focus of the work area and determining the time for implementing forest and land fire prevention and control activities in Riau Province.

In the context of mitigating forest and land fires, disaster status cannot be removed. Determining the status of a forest and land fire disaster will influence the response that the government must take in efforts to overcome and control forest and land fires. Related to this, in the previous subchapter we have analyzed a lot of stakeholder perceptions which tend to indicate that they agree with the use of the results of physical monitoring of peatlands in determining the status of forest and land fire disasters. As coordinator of disaster activities, BNPB together with BPBD Riau Province has a key role in providing input to regional and central governments in determining the status of certain disasters. In accordance with interviews conducted, the results of physical monitoring of peatlands, such as the wetness of peatlands in this research, are also considered helpful in identifying potential forest and land fires in Riau Province.

> *"For a long time, determining the status of disasters, whether on alert in districts or provinces, was still carried out by tending to rely on historical data. This means that when there is minimal rain and there are already hotspots, there are usually areas that have declared emergency alert status. If there are findings such as the results of observing the wetness of peatlands, then we can actually use it as an indicator that needs to be considered in assessing and determining disaster status, especially at the Emergency Alert level because at that level our response is important, so that forest and land fires do not spread and can be done immediately. controlled." (MA, Prevention Coordinator, BPBD Riau Province)*

> *"The results of observations on peatlands will be very helpful in the realm of preparedness, especially at the Emergency Alert level. Fluctuations in the wetness of peatlands, for example, if observed with a large number of observations, will certainly be very useful in determining strategies that must be taken and implemented immediately, so that if possible, forest and land fires do not occur, or if they have already happened, so that they can be dealt with quickly and other areas do not catch fire. " (BSP, Head of Operations Control Center, BNPB)*

> *"The key is how observations (of peatland wetness) like this are reproduced. So that we can get data that truly represents the condition of peat in Riau Province as a whole. "This is important so that forest and land fire mitigation can be planned better, especially regarding the accuracy of timing of forest and land fire control activities and their regional focus." (WPA, Head of Rapid Assessment and Operations Planning Support Division, BNPB)*

Based on the interpretation of the results of interviews conducted with representatives of stakeholders related to forest and land fires, this research can synthesize several aspects of the concept of forest and land fire mitigation by utilizing the results of physical monitoring of peatlands. The government, as the party that plays the most role in forest and land fire mitigation activities, generally has a role and responsibility for providing physical monitoring instruments for peatlands, research and development of monitoring results, and selection of responses for mitigating and controlling forest and land fires. The participation of community groups can be realized in the use of the results of physical monitoring of peatlands for related community operational activities such as "*So far, determining disaster status, whether on alert in the district or province, is still carried out by tending to rely on historical data. This means that when there is minimal rain and there are already hotspots, there are usually areas that have declared emergency alert status. If there are findings such as the results of observing the wetness of peatlands, then we can actually use it as an indicator that needs to be considered in assessing and determining disaster status, especially at the Emergency Alert level because at that level our response is important, so that forest and land fires do not spread and can be done immediately. controlled.*" (MA, Prevention Coordinator, BPBD Riau Province).

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Based on the interpretation of the results of interviews conducted with representatives of stakeholders related to forest and land fires, this research can synthesize several aspects of the concept of forest and land fire mitigation by utilizing the results of physical monitoring of peatlands. The first is the division of roles of the main stakeholders, which are divided into three groups, namely Government, Private and Community. The government, as the party that plays the most role in forest and land fire mitigation activities, generally has a role and responsibility for providing physical monitoring instruments for peatlands, research and development of monitoring results, and selection of responses for mitigating and controlling forest and land fires. The participation of community groups can be realized in the use of the results of physical monitoring of peatlands for operational activities of related communities such as the Fire Care Community (MPA). Apart from that, community groups can also play a role in assisting with the installation and monitoring of physical instruments for peatlands. Meanwhile, the private sector can play an active role by contributing to physical observations of peatlands in their work areas or concessions. Licensing access to physical observations of peatlands in the working areas of private parties such as HTI companies, for example, will open up opportunities for more areas to be directly observed, so that the density of physical observations of peatlands will be better.

Another aspect is the role and responsibility of stakeholders, the next aspect in the concept of mitigating forest and land fires based on physical observations of peatlands such as the wetness of peatlands in this research is how to formulate the wetness conditions of peatlands to be implemented in determining the disaster status of forest and land fires along with the responses given.

	Emergency alert	Emergency Response
Emergency alert	• The majority of peat areas in Riau Province are at a peatland wetness level of Medium - Dry • Monitored hotspots • Enter during the dry months (January, February, June, July, August, September)	• The majority of peat areas in Riau Province are at the dry peatland wetness level • Monitored hotspots • Enter during the dry months (January, February, June, July, August, September)
Response	• Preparing ground patrols around areas with Medium-Dry peatland wetness levels • Priority direction for forest and land fire mitigation activities through air (weather modification and water bombing) for wetting land to reduce the potential for widespread forest and land fires • Setting up a canal blocking engineering system to help wetting peatlands	• Preparing ground patrols around areas with wet levels of dry peatlands • Priority briefing on forest and land fire mitigation activities via air (weather modification and water bombing) for direct fire extinguishing

Fig. 3 Wetness-based forest and land fire mitigation concept peatlands

Fig. 3 is the result of the formulation of a forest and land fires mitigation concept based on peatland wetness which is compiled from a combination of a matrix of peatland wetness, forest and land fires disaster status, and the response that should be taken in each condition. Based on the calculation results, 3 levels of peatland wetness were obtained, namely Wet, Medium and Dry. These three levels can be implemented in forest and land fire disaster status at the Emergency Alert and Emergency Response levels. Responses at each level of disaster status were summarized through the results of in-depth interviews with several key informants who were representatives of forest and land fire stakeholders in Riau Province.

In the overall analysis in this research, peatland wetness is one of the parameters that can play a role in forest and land fire mitigation activities. Several findings such as peatland wetness categories, which are compiled based on threshold values for humidity and temperature in peatlands, can help provide the current conditions of peatlands in Riau Province. The wetness of peatlands is also considered to be one of the indicators to be considered in determining the status of forest and land fires disasters. Although at the same time stakeholders related to forest and land fires also highlighted several aspects that need to be improved in the use of peatland wetness monitoring results such as in this research, in principle, the results of monitoring parameters related to forest and land fires should indeed be used and utilized to develop forest fire mitigation activities that prioritize the principles preventive.

Same like other disasters, forest and land fires in Indonesia are a challenge that must be faced through various approaches. In sustainable development, the importance of disaster mitigation is seen as a form of protecting the continuity of living creatures and the environment on this earth, especially as many disasters actually occur due to intervention from human activities (Goto & Picanço, 2021; Monte et al., 2021; Rana et al., 2021). Therefore, the importance of understanding disasters, including reducing risks, is importantDisaster risk prevention and management efforts are important points in the larger framework of disaster mitigation that can be achieved (Kusumastuti et al., 2021; Ogra et al., 2021). This section explains the further elaboration of the findings in this research on previous research as well as providing theoretical reflection. Apart from that, in this section the research results will be synthesized with the principles of Environmental Science and sustainability aspects in relation to the research theme.

Like a hydrometeorological disaster, forest and land fires do have several variables that influence it. The characteristics of areas that frequently burn when forest and land fires occur in Indonesia are dominated by peat land cover, posing a threat to the ecological function of peat. Apart from damaging ecological functions, forest and land fires on peatlands also have an impact on socio-economic aspects considering that quite a lot of human activity is carried out on peatlands (Dargie et al., 2017; Uda et al., 2017). The importance of observing peatland variables cannot be separated from the characteristics of the peatland itself. The porosity of peat and its ability to absorb water optimally in wet conditions and then release it in dry conditions makes peat soil like a sponge. Apart from that, peat soil which is formed due to the accumulation of organic material makes it laden with 'fuel' which of course will spread fire very easily. This phenomenon is often called peat smouldering which will be very difficult to extinguish if a fire below the peat surface has occurred (Cochrane, 2015; Huang et al., 2016; Goldstein et al., 2020). Therefore, in the context of forest and land fires disaster mitigation, especially in peatlands, apart from the importance of looking at historical weather parameters, it is also necessary to observe the physical condition of the peat which is measured directly beneath the peat soil itself, such as humidity and temperature (Bonn et al., 2016; Wilkinson et al., 2018).

In disaster mitigation activities, the importance of early detection and preparedness is often the key to success in reducing potential disaster risks. Monitoring peatland wetness which can be used as an indicator in early detection and strengthening disaster preparedness is also in accordance with several previous research results (Evans et al., 2019; Miettinen et al., 2017). The results of this study are also in line with research conducted by Aguilera et al. (2016) who explained that spatial wetness conditions in wetlands and peat can indicate the potential for the emergence of hotspots. In other research conducted by Yananto et al. (2022), also revealed that peatland wetness, one of which is measured by peatland humidity, is able to provide information on the potential for forest and land fire areas in Riau Province. In this research, satellite data was also used to help complete physical observation data on peatlands which were measured directly. The research results show that peatland wetness, which is expressed from the humidity and temperature in the peatland, can be used as an indicator of hotspots, and can also be used as a complement in reviewing peat ecosystem governance, especially in observing physical conditions other than just measuring groundwater level (TMAT), as explained in Minister of Environment and Forestry Regulation 15/2017.

To Disaster mitigation activities basically start from before a disaster occurs. So the aspect of preparedness and early detection as raised in this research is one form of improvement in disaster mitigation. Burns (2016) explains that to achieve sustainable environmental management, response to disasters plays an important role, especially to avoid serious environmental damage. The use of technology to support disaster activities is not only able to provide input for environmental elements. By better detecting the potential for forest and land fires, losses in socio-economic aspects such as losses due to burned land or disruption of human life (both health and activities) can be reduced.

4. Conclusions

Peatland wetness can serve as an indicator for detecting potential hotspot emergence. Peatlands categorized as Dry to Medium in wetness are spatially associated with a high concentration of hotspots in the study area, especially during dry months. Stakeholder perceptions indicate agreement on the use of peatland wetness monitoring to inform decisions regarding the disaster status of forest and land fires. By conducting real-time monitoring of peatland wetness, which can provide information across multiple areas, the potential for forest and land fires can be detected earlier. This early detection is crucial as it informs the necessary responses and mitigation activities that stakeholders must undertake. Peatland wetness-based forest and land fire mitigation is an effort to reduce disaster risks by utilizing monitoring results that incorporate peatland wetness values to enhance preparedness. This approach involves relevant stakeholders, including government groups, the private sector, and the community.

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