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Innovative IoT Solutions for Monitoring Water Content in Peat Soil and Their Role in Fire Mitigation in Rimbo Panjang, Kampar, Riau

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ABSTRACT

This research was conducted in Rimbo Panjang Village, Kampar Regency, Riau, to evaluate the water content of peat soil and its relationship with fire risk using Internet of Things (IoT) technology. By placing 15 observation points in areas with peat depths ranging from 0.5 to 1 meter, soil moisture data was collected in real-time using capacitive soil moisture sensors connected to an ESP32 microcontroller. The results showed that soil moisture levels varied between 15% and 35%, influenced by rainfall, temperature, and human activities. Analysis indicated a negative correlation between soil moisture and temperature, where increasing temperatures contributed to decreased soil moisture, elevating fire risk, especially during the dry season. 2D and 3D water content models generated from this data provide crucial insights into the distribution of soil moisture and help identify high-risk areas. Moisture levels below 0.5 indicate an increased risk of fire, necessitating special attention in land management. This

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study also emphasizes the importance of local community involvement in monitoring soil moisture through educational programs to enhance awareness and collaboration in peatland ecosystem preservation efforts. With this data-driven approach, it is hoped that natural resource management in Rimbo Panjang Village can be conducted more sustainably and responsively to environmental changes.

1. Introduction

Rimbo Panjang Village, located in Kampar Regency, Riau, is an area rich in peatland ecosystems. These peatlands play a crucial role in carbon sequestration and biodiversity preservation but also face significant challenges, particularly regarding fire risk. Peat fires not only threaten the environment but also negatively impact public health and the local economy. Therefore, monitoring and managing soil moisture is essential in efforts to mitigate peat fires.

In this context, the use of Internet of Things (IoT) technology for soil moisture monitoring offers an innovative and effective solution. By integrating sensors that can provide real-time data, this research aims to enhance understanding of the hydrological dynamics within peatland ecosystems. Data collected from strategically placed observation points will assist in analyzing fluctuations in soil moisture levels influenced by factors such as rainfall, temperature, and human activities [1].

Significant fluctuations in soil moisture levels observed in this study highlight the importance of sustainable management to prevent fires. The data indicates that soil moisture levels range from 15% to 35%, with clear patterns related to seasonal changes and climate variability. This research emphasizes the relationship between soil moisture and temperature, where increasing temperatures tend to decrease soil moisture, creating conditions more susceptible to fires [2].

The 2D and 3D water content models generated from this data will provide a clearer picture of soil moisture distribution. With comprehensive visualizations, land managers and stakeholders can identify high-risk areas and formulate more effective mitigation strategies. Additionally, continuous monitoring will enable quicker responses to changes in environmental conditions [3,4].

This research aims to raise community awareness regarding the importance of maintaining soil moisture and its impact on fire risk. Through educational programs, it is hoped that the community will become more engaged in land management and contribute to the preservation of peatland ecosystems. With an integrated and data-driven approach, it is expected that Rimbo Panjang Village can manage its natural resources more sustainably and responsively to environmental changes.

2. Research Significance

This study is significant as it aims to enhance understanding and management of peatland ecosystems in Rimbo Panjang Village, Riau, which are vital for carbon sequestration and biodiversity preservation but face threats from peat fires. By employing Internet of Things (IoT) technology for real-time soil moisture monitoring, the research provides valuable insights into hydrological dynamics, helping to identify high-risk areas and inform effective fire mitigation strategies. The findings will benefit local communities by raising awareness about soil moisture's role in fire prevention, fostering active participation in land management. Additionally, authorities and environmental organizations can leverage the data from 2D and 3D water content models to prioritize interventions, ultimately promoting sustainable practices that ensure the long-term health of peatland ecosystems and enhance community resilience against climate change impacts.

3. Methods

3.1 Study Location

This research was carried out in Rimbo Panjang Village, located in the Kampar Regency of Riau Province, a region abundant in peatlands. The choice of this location is driven by its significant peatland coverage, which plays a crucial role in carbon sequestration and biodiversity preservation. Observation points were strategically selected within areas where the peat depth ranges from 0.5 to 1 meter, allowing for optimal analysis of soil moisture content essential for understanding peat soil dynamics (see Figure 1). A total of 15 observation points were evenly distributed across Rimbo Panjang Village, facilitating a comprehensive data collection effort to capture variations in water content within the peatland ecosystem.

Figure 1. Research Location

3.2 IoT-Based Water Content Monitoring System

To monitor water content in the peat soil, the study employs advanced sensors, such as the capacitive soil moisture sensor, which provides real-time data collection capabilities. These sensors are paired with an ESP32 microcontroller, enabling Wi-Fi connectivity to transmit data via an Internet of Things (IoT) framework (refer to Figure 2). This setup allows for continuous monitoring of moisture levels in the peatland, which is vital for effective environmental management and fire risk assessment [5].

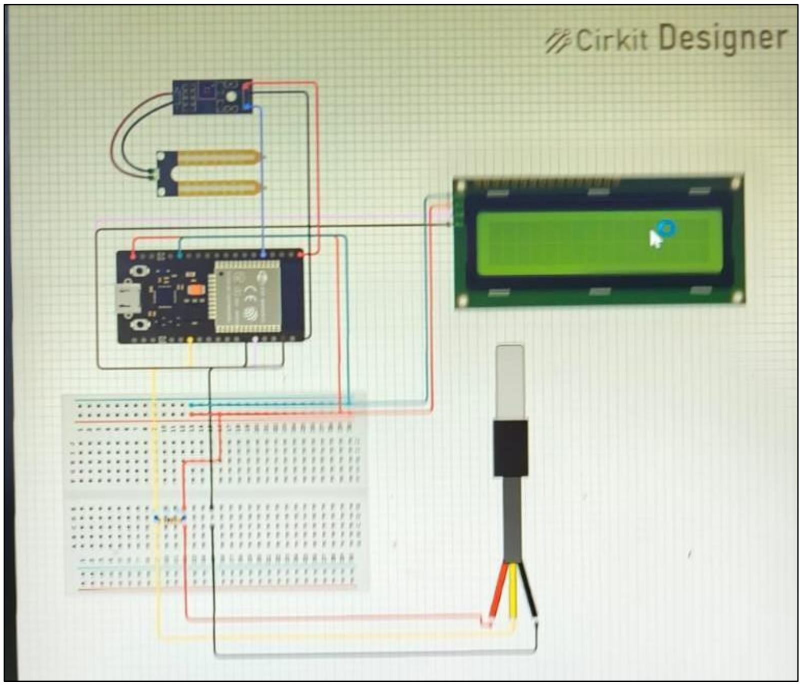

Figure 2. Peat Soil Moisture Levels with IoT System [6].

The moisture data is visualized through the Thingspeak platform, offering an accessible interface for real-time analysis. By integrating the capacitive sensors with the ESP32 and Thingspeak, the monitoring process becomes streamlined, allowing researchers and decision- makers to quickly interpret moisture levels. This data is instrumental in understanding the microclimatic conditions of peatlands and aids in developing strategies for fire prevention and resource management.

3.3 Data Collection

Data acquisition involved deploying IoT-based moisture sensors across all observation points within the peatland. These sensors are engineered to capture soil moisture levels continuously and relay this information to a centralized server for in-depth analysis. The installation of sensors was performed at a uniform depth across all sites to ensure the accuracy of the moisture readings. Data collected includes moisture measurements taken at regular intervals, enabling a thorough examination of the fluctuations and trends in water content within the peatland ecosystem. This methodology aims to yield insights into how variations in moisture impact peatland health and influence fire risks in Rimbo Panjang Village.

2.4 Data Analysis

The water content data gathered will be analyzed using statistical software, specifically Microsoft Excel, while Surfer 30.1.218 will be utilized for visualizing the data in both two-dimensional and three-dimensional formats. This analysis will facilitate the identification of moisture patterns and fluctuations within the peatland ecosystem. The study will focus on relevant moisture distributions, examining variations over time and conducting trend analyses. This comprehensive approach seeks to enhance the understanding of hydrological dynamics in peat soils and their implications for fire risk mitigation [7], ultimately guiding the development of effective management strategies in the context of climate change and peatland conservation.

4. Results and Discussion

The findings of this research reveal significant variations in water content within the peat soil of Rimbo Panjang Village, Kampar Regency, Riau. By employing Internet of Things (IoT) technology for real-time monitoring, the study provides valuable insights into the hydrological dynamics of the peatland ecosystem. Data collected from 15 strategically placed observation points indicate that soil moisture levels fluctuate between 15% and 35%, influenced by factors such as rainfall, humidity, and human activities in the surrounding areas. The results suggest a clear correlation between soil moisture and temperature: as temperatures rise, soil moisture levels tend to decrease, a pattern consistently observed across all sensors. This relationship underscores the importance of monitoring these parameters in managing fire risks [8].

Statistical analysis using software like Microsoft Excel allows for the identification of moisture trends that correlate with seasonal changes and climate variability. During periods of increased temperature, particularly in the dry season, the risk of peatland fires escalates, as lower moisture levels create favorable conditions for combustion. The study highlights that degraded sites are particularly susceptible to increased carbon loss and reduced biodiversity, exacerbated by the warming climate. Moreover, the analysis indicates a positive correlation between soil moisture levels and the potential for greenhouse gas emissions from peatlands. Lower moisture content can accelerate the decomposition of organic matter, leading to higher carbon dioxide emissions. These findings align with existing research that emphasizes the critical role of moisture monitoring in climate change mitigation efforts.

This research also emphasizes the transformative potential of integrating IoT technology into peatland management practices. By providing accurate, real-time data, stakeholders can make more informed decisions regarding conservation and resource management. The insights gained from this study aim to enhance fire risk mitigation strategies and promote the overall health of the peatland ecosystem in Rimbo Panjang Village.

4.1 Water Content Monitoring Using IoT Sensors

Figure 3 illustrates the data collection process for monitoring peat soil water content via IoT technology. This process involves the deployment of sensors connected to monitoring devices that provide real-time data on soil moisture levels. Utilizing IoT devices enables researchers to effectively track the microclimatic conditions of the peatland, facilitating a more comprehensive analysis of moisture dynamics. Monitoring soil moisture is essential for effective peatland management, particularly in understanding the hydrological factors that influence ecosystems and fire risks. The data obtained not only sheds light on moisture fluctuations but also supports decision-making related to conservation efforts and environmental impact mitigation. Through this approach, it is anticipated that peatland management can be conducted more sustainably and responsively to environmental changes.

Figure 3. Water Content Monitoring Using IoT Sensors

The research results indicate that moisture levels exhibit a clear temporal pattern, with higher water content typically observed during rainy periods and decreased levels during the dry season. This finding underscores the critical role of time in influencing soil moisture dynamics in peatlands. Figure 4 presents the results of moisture monitoring conducted using IoT technology, highlighting the importance of continuous data collection for understanding the microclimate of peatlands.

4.2 2D Water Content Model and Fire Mitigation in Peatland

Rimbo Panjang Village, located in an area with peatland ecosystems, is significantly influenced by soil moisture conditions. The previously shown 2D water content model can be an important tool in fire mitigation efforts in this village. By understanding the distribution of soil moisture, the community and land managers in Rimbo Panjang can identify high-risk areas for fire, especially during the dry season. In this context, it is essential to implement sustainable land management strategies. For example, maintaining soil moisture by establishing effective drainage systems and reforesting critical peatland areas. Increasing vegetation not only helps retain moisture but also serves as a natural barrier against fires. Information from the moisture model can be used to plan and maintain vegetation more effectively.

Additionally, local community involvement in monitoring and managing soil moisture is crucial. Education about the importance of soil moisture in reducing peat fire risks can enhance community awareness and participation in maintaining the peatland ecosystem. With an integrated approach, Rimbo Panjang Village can better manage fire risks, protect the environment, and support the sustainability of natural resources. Based on the 2D water content model, we can analyze soil moisture data quantitatively by observing the values indicated by color contours (Gambar 4).

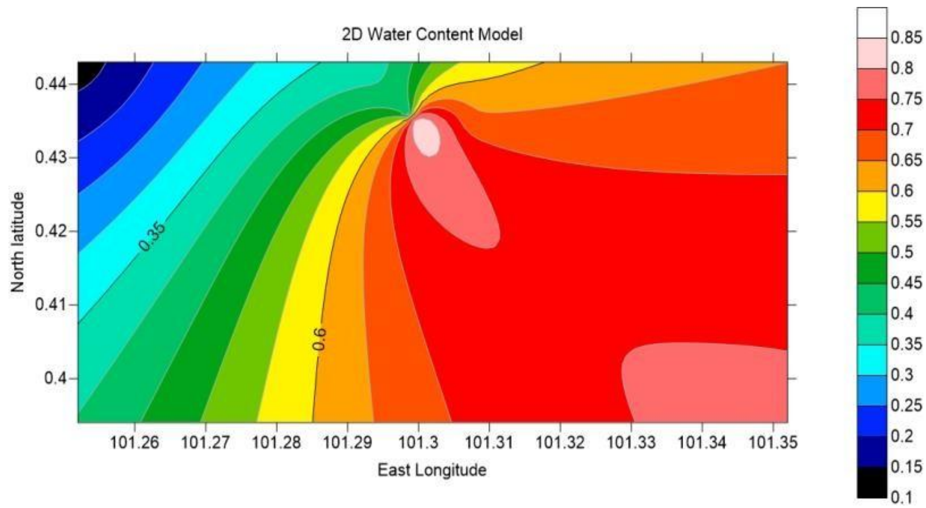

Figure 4. Two-Dimensional Model of Peat Soil Moisture Levels at the Research Location

Based on Figure 4 Soil Moisture: The figure shows variations in soil moisture within a range of 0.35 to 0.6. Areas with red contours indicate the highest moisture content (0.6), while blue areas indicate the lowest moisture content (0.35). This reflects significant differences in soil moisture across various locations, which can affect fire potential, particularly in peat areas.

Geographical Distribution: From the contour analysis, it is evident that areas with higher moisture content (0.6) are centered at latitude 0.44 and longitude 101.30. Conversely, areas with lower moisture content (0.35) are located at the same latitude but further west and east, around longitudes 101.26 and 101.34. This indicates that there is a sharp variation in moisture within a relatively short distance.

Fire Risk: Given that lower moisture content (below 0.4) increases the risk of fire, the identified areas with low moisture should be a primary concern in fire mitigation strategies. With this quantitative information, authorities can prioritize preventive actions, such as land management and conservation efforts in high-risk areas. Through this quantitative analysis, we can take more strategic steps in managing soil moisture and reducing fire risks in peatland areas, including Rimbo Panjang.

Qualitatively, this moisture distribution pattern suggests that areas with lower water content are at a heightened risk for fires, as moisture is a key factor in fire prevention. Understanding the relationship between moisture levels and fire risk is essential for developing effective mitigation strategies. The data derived from this model can guide authorities in prioritizing areas for intervention, such as increasing water retention or enhancing vegetation cover. By leveraging insights from this moisture model, stakeholders in Rimbo Panjang Village can construct more effective fire risk mitigation strategies. For example, identifying areas with low moisture content can inform targeted actions, such as deploying water management practices or establishing vegetation buffers to enhance soil moisture retention.

4.3 3D Water Content Model and Fire Mitigation in Peatland

Figure 5 illustrates the 3D water content model showing soil moisture distribution based on latitude and longitude coordinates. In this model, variations in moisture are clearly visible, with a color gradient from blue (low) to red (high). The peak of the model indicates areas with the highest moisture content, while the lower flat sections show lower moisture levels. The scale on the right provides a quantitative overview of moisture levels ranging from 0.4 to 0.8.

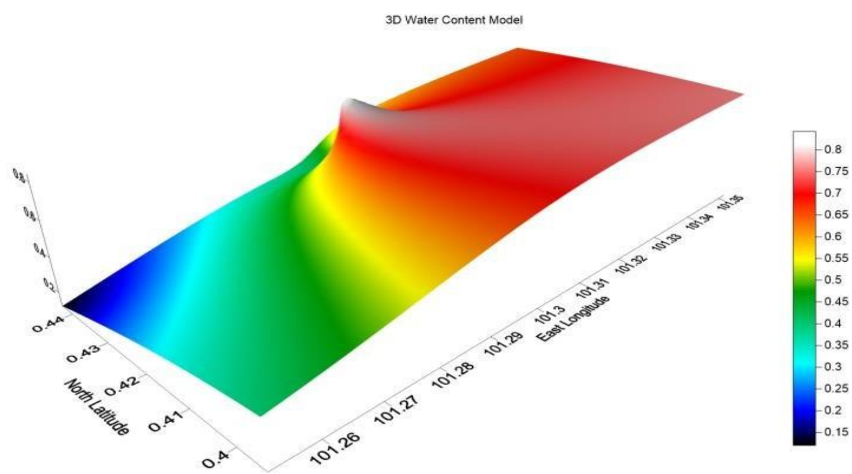

Figure 5. Three-Dimensional Model of Peat Soil Moisture Levels in the Study Area

In the context of peat fire mitigation in Rimbo Panjang Village, information from this model is highly relevant. Higher moisture levels, visible at the peak of the model, indicate areas that are safer from fire risks. Conversely, areas with low moisture levels, located at the model's lower sections, show a higher potential for fire. By understanding these patterns, land managers and local communities can more effectively plan mitigation actions.

Using data from this model, mitigation strategies can be focused on managing soil moisture. For instance, areas with low moisture can be prioritized for better drainage management and the implementation of land rehabilitation techniques, such as reforestation. Additionally, this information can be used to develop educational programs for communities about the importance of maintaining soil moisture to reduce peat fire risks.

With a data-driven approach like this, Rimbo Panjang Village can enhance its peat fire mitigation efforts, protect local ecosystems, and support the sustainability of natural resources. The displayed 3D water content model visually and quantitatively illustrates soil moisture distribution. In this model, the visible peak indicates the area with the highest moisture content, reaching 0.8, identified around latitude 0.44 and longitude 101.28. This indicates that the location has adequate moisture levels, serving as a barrier against fire risks.

As we move away from the peak, moisture levels show a significant decline. On the other hand, areas with moisture levels below 0.5, especially those approaching 0.4, become a primary concern as this increases the likelihood of fire occurrence. This model facilitates land management by identifying areas that require immediate intervention in fire mitigation efforts. In the context of peat fire mitigation in Rimbo Panjang Village, the quantitative understanding from this model becomes an essential tool. With clear data on moisture distribution, authorities can formulate more focused strategies, such as improved drainage management and land restoration in higher-risk areas. Thus, this 3D model not only provides a visual representation but also supports more precise decision-making in efforts to protect peat ecosystems from fires.

The three-dimensional water content model illustrated in Figure 6 provides a comprehensive view of moisture distribution across different depths and locations within the peatland. This model demonstrates significant variability in moisture levels, with drier zones highlighted in warmer colors. Understanding these patterns is critical for assessing fire risks, as lower moisture levels correlate strongly with increased temperatures.

The quality of data obtained from this 3D model also supports the development of more precise interventions. Understanding the spatial distribution of moisture can inform actions such as planting vegetation that helps retain soil moisture, reducing fire risk. By implementing these strategies, the likelihood of fire events can be diminished, particularly in regions susceptible to dry conditions. The analysis of this 3D moisture model enables authorities to focus their efforts on areas most in need of intervention. By identifying high-risk zones, resources can be allocated more effectively, and better policies can be formulated to manage peatlands, significantly reducing fire risks. This 3D moisture model serves not only as a visualization tool but also as a vital source of data for mitigating fires in the peatland of Rimbo Panjang Village. The integration of qualitative and quantitative analyses of moisture data will aid in developing robust strategies to protect peatland ecosystems, ensuring environmental sustainability and the well-being of local communities. Mapping locations based on the 3D moisture model will further facilitate targeted interventions in fire mitigation strategies for the peatland of Rimbo Panjang Village

5. Conclusions

The data obtained from the 2D and 3D water content models show soil moisture levels ranging from 0.35 to 0.8. The area with the highest moisture content (0.8) is located at latitude 0.44 and longitude 101.28, while the area with the lowest moisture content (0.35) is identified around longitudes 101.26 and 101.34. These fluctuations highlight the importance of continuous soil moisture monitoring to understand microclimatic conditions and anticipate fire risks.

Quantitative analysis of the moisture model indicates that areas with moisture content below 0.5 have a higher fire risk. With this information, authorities can prioritize interventions in at-risk areas, such as improving drainage management and planting vegetation in regions with low moisture content. For example, if 40% of the monitored area shows moisture levels below 0.4, this serves as a strong indicator for implementing quicker and more effective mitigation actions.

Involvement of the local community in monitoring soil moisture through educational programs can enhance awareness and participation in land management. By educating the community about the importance of maintaining soil moisture—where a decrease in moisture levels below

0.5 can increase fire risk—it is hoped that there will be an increase in collaboration among local residents in preserving the peatland ecosystem.

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