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## 2 Modeling of groundwater level fluctuation in the tropical peatland area of Riau, Indonesia

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**Abstract.** The groundwater level (GWL) is a key parameter for assessing the level of fire risk in the peatland so that if the predicted fluctuations of GWL in the next few days or weeks can be predicted; the risk of peat fire can also be estimated. The purpose of this study is to develop a hydrological model using regression analysis that can be used to predict GWL in the peatland. The data used for modeling were historically recorded of rainfall and GWL fluctuations from SESAME equipment in Dompas village, Riau, Indonesia. Regression analysis was carried out using four data length scenarios, such as one-month, two-months, three-months, and six-months to find out which time period could represent hydrological conditions in the field. The results showed that the regression analysis using three-months and six-months data represented the best results of the GWL prediction with a correlation coefficient of 0.95. However, the prediction using one-month and two-months data represented reasonable prediction results with a correlation coefficient of 0.86 and 0.89 respectively. Judging from observed and predicted GWL that was always in the lower position than 0.4 m depth, this area was always in the high risk of peat fire throughout the year.

### 1. Introduction

Peatlands are a kind of soil that is formed from accumulated organic matter deposits. These deposits are formed naturally from weathering vegetation that grows above the ground in a period of hundreds of years. The decomposition process of materials is hampered due to anaerobic and wet conditions, this causes peat soils to be found in swamps. Peat has unique physical characteristics, which are able to absorb water very much. The pristine peatlands consist of almost 90% water and the remaining 10% is residual decomposed plant material [1], therefore peat in natural conditions (undisturbed) will always be wet and humid. Therefore, the hydrological process is very important in the management of peatlands [2]. In the dry season, the peat soil functions as a water-retaining layer and releases water slowly. Peat water appears brownish-black, because of the long-term submergence of various organic materials on peatlands [3].

Almost every year, the haze disaster because of peatland fire occurs in Indonesia, especially in Kalimantan and Sumatra island which causes huge economic losses and harmful public health problems. The fires also cause a decrease of peat soil thickness of 10-15 cm and resulted in 100% mortality of soil flora and fauna [4]. Unlike the rapid occurrence of earthquake disasters [5], peatland fires tend to occur slowly which usually begins with lighted rainfall events, so that actually there is still sufficient time to prepare an emergency response. The peatland fires are very difficult to be extinguished because the fires penetrate to the below-ground of peatland. The historical evidence shows that only rainfall can stop the peat fire completely [6], [7]. To anticipate the possibility of disaster recurring, prevention efforts are needed. Based on this historical experience, it is necessary to have a device that can be used as a basis for



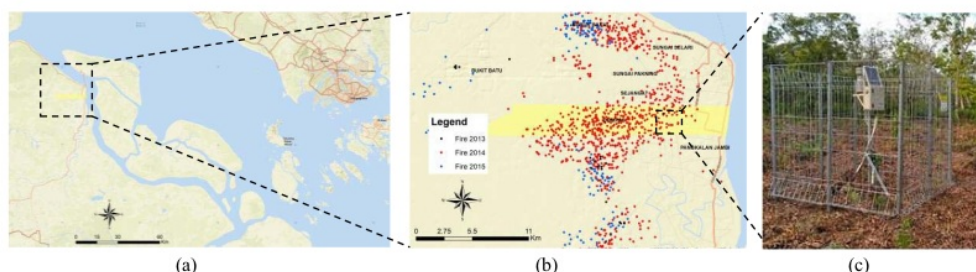
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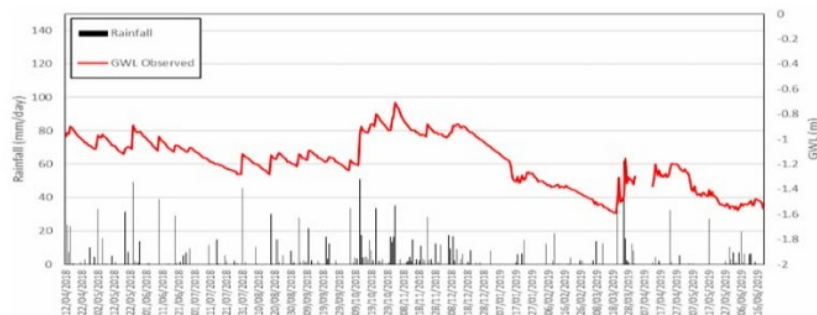
early warning of the peatland fires risk, so that efforts for fire prevention can be prepared as early as possible.

The GWL is a key parameter for assessing the level of fire risk in peatlands [8], [9], so that if the GWL fluctuations in the next few days or weeks can be predicted, then the risk of fire also can be estimated. Tropical peatlands will be burnt easily if they are dry with a depth of GWL more than 0.4 m [10]. To be able to find out the level of risk of drought and fires on peatlands, the Government of the Republic of Indonesia through the Peat Restoration Agency (BRG) monitors GWL in real-time using the SESAME (Sensory Data Transmission Service Assisted by Midori Engineering) tool. The SESAME tool was installed in several peatland areas to monitor GWL, temperature and rainfall data.

The purpose of this study is to develop a hydrological model using regression analysis that can be used to predict GWL fluctuation in peatlands so that it can be used to predict the level of risk of land fires as a basis for early warning. The SESAME tool in Dompas village, Bengkalis Regency, Riau Province was picked up as a study site for developing the model. Historically, the village has severe peat fire damage in 2013, 2014 and 2015. The results of this research are presented in this paper.



**Figure 1.** Study area at Dompas village, Bengkalis Regency (a), the fire history in 2013, 2014, 2015 (b), and the SESAME tool at Dompas village (c).



**Figure 2.** The historical data of GWL fluctuation and rainfall from the SESAME at Dompas village, Bengkalis Regency

## 2. Method

### 2.1. Material Study Area and Data Acquisitions

This research was investigated at Dompas village, Bengkalis Regency, Riau province, Indonesia which is located in Sungai Rokan-Sungai Siak Kecil Peatland Hydrological Unit (PHU) (See Figure 1a). The Dompas village and many villages in Bengkalis have severe peat fire in 2013, 2014 and 2015. The historical fire spots at Dompas village in 2013, 2014 and 2015 are presented in Fig. 1b. A SESAME tool has been installed by Peat Restoration Agency, Republic of Indonesian (BRG-RI) at Dompas village to

monitor the GWL fluctuation for a fire risk alert in this area Since April 2018 (Fig. 1c). The recorded data from this tool is presented in Fig. 2.

## 2.2. Basic Concept for Modeling

The GWL information in the peatlands is very important for the management and prevention of peatland fires, therefore prediction of GWL in peatlands is very important to do. Spatial and temporal groundwater prediction can be done both by modeling and mapping GWL [11] and by processing remote sensing data [8]. However, the results of these predictions and modeling are highly dependent on existing satellite data globally with a detailed resolution.

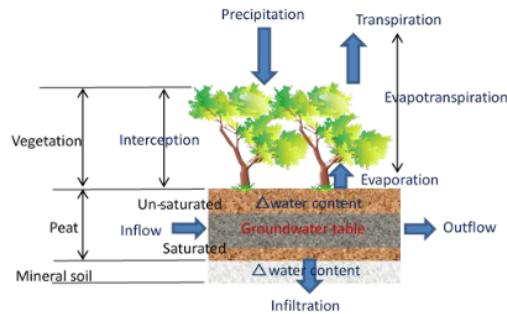
The GWL prediction in the peatlands can be carried out by mathematical modeling and a statistical approach based on the concept of water balance in peatlands as presented in Figure 3 [12]. Based on the basic principle of water balance for modeling tropical peatland as presented in Fig.3, the daily fluctuation of GWL is estimated using the difference between an increase of GWL due to the daily rainfall and a decrease of GWL due to daily evapotranspiration. It can be formulated mathematically as follows:

$$dW = dW_{\text{rain}} - dW_{\text{loss}} \quad (1)$$

where,  $dW$  is the daily GWL change,  $dW_{\text{rain}}$  is the increases of daily GWL because of rainfall, and  $dW_{\text{loss}}$  is a decrease in daily GWL because of evapotranspiration and runoff. The  $dW_{\text{loss}}$  and  $dW_{\text{rain}}$  parameters are a correlation which is a function of each evapotranspiration and rain. The  $dW_{\text{loss}}$  and  $dW_{\text{rain}}$  parameters represent the response of GWL fluctuation because of rainfall and losses in the peatland hydrological cycles. Thus, the GWL in the next day can be estimated with the following formulation.

$$W_{n+1} = W_n + dW_{\text{rain}} - dW_{\text{loss}} \quad (2)$$

where,  $W_{n+1}$  is the estimated of GWL in the next day and  $W_n$  is the GWL in the previous day.



(Source: Takahashi, 2017)

**Figure 3.** The basic principle of water balance for modeling tropical peatland

## 2.3. Modeling Procedures

Using the historical data of GWL and rainfall, the response of GWL fluctuation was recorded statistically. The  $dW_{\text{rain}}$  which is defined as the correlation between the raised of GWL and the amount of rainfall was developed. However, the  $dW_{\text{loss}}$  is defined as the correlation between daily GWL loss and GWL distance from ground surface. The  $dW_{\text{rain}}$  and  $dW_{\text{loss}}$  parameters were analyzed using regression analysis to understand the trend and the parameter determination. The determination coefficient ( $R^2$ ) is a statistical measure to describe how close the data are to the fitted regression line. It is the percentage of the response variable variation that is explained by a linear model. The higher the determination coefficient, the better the model fits to the data. The value of the determination coefficient will have between 0 and 1. The regression analysis was carried out for both parameters using four data length scenarios, such as 1-month,



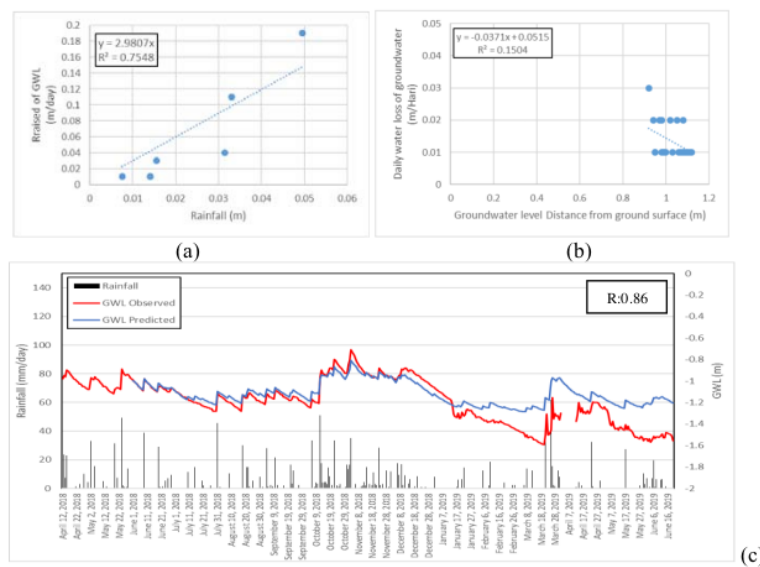
2-months, 3-months, and 6-months to find out which time period could represent the best hydrological conditions like in the field.

The GWL for the next day can be predicted using eq. 2 using the regression equations of  $dW_{\text{rain}}$  and  $dW_{\text{loss}}$  from the regression analysis. The predicted GWL was compared with the observed GWL to know the correlation between them. The correlation coefficient is a statistical measure that calculates the strength of the relationship between those variables. The values range between -1.0 and 1.0. A calculated number is greater than 1.0 or less than -1.0 means that there was an error in the correlation measurement. A correlation of -1.0 shows a perfect negative correlation, while a correlation of 1.0 shows a perfect positive correlation. A correlation of 0.0 shows no relationship between the movement of the two variables [17]. The strength of the relationship varies in degree based on the value of the correlation coefficient. Experts do not consider correlations significant until the value surpasses at least 0.8. However, a correlation coefficient with an absolute value of 0.9 or greater would represent a very strong relationship.

### 3. Result and Discussion

#### 3.1. Modeling using one-month data

The regression analysis of  $dW_{\text{rain}}$  and  $dW_{\text{loss}}$  using 1-month data of May 2018 is presented in Fig. 4a and Fig. 4b respectively. There were six rainfall events during May 2018. The data in April 2018 was not used in this modeling because there were only two days of rainfall events. The determination coefficients of the  $dW_{\text{rain}}$  and  $dW_{\text{loss}}$  regression analysis were 0.7548 and 0.1504 respectively. It means that the rainfall has a response about 75.48% to the raised of GWL, and the GWL distance from the ground surface has a response about 15.04% to the daily water loss of GWL.



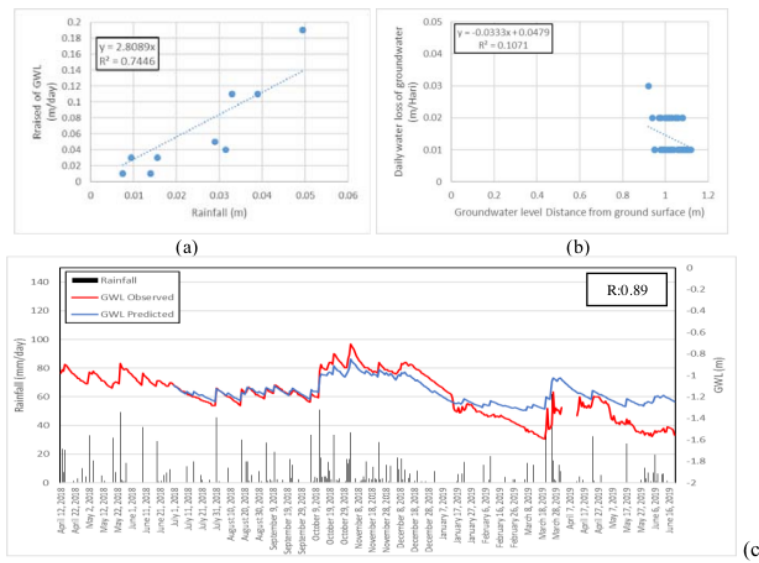
**Figure 4.** The modeling process of  $dW_{\text{rain}}$  (a),  $dW_{\text{loss}}$  (b) and comparison of predicted GWL with observed GWL (c) using one-month data (May 2018)

Using rainfall data input and the GWL distance from the ground surface as well as the equation resulted from regression analysis of  $dW_{\text{rain}}$  and  $dW_{\text{loss}}$ , the GWL for the next day was predicted using eq.2. The result of the GWL prediction using those data and equations was presented in Fig. 4c. The figure

shows that the predicted GWL has a good pattern with the observed GWL from June 2018 to January 2019. The correlation coefficient between the predicted GWL and observed GWL was about 0.86. This means that the predicted GWL has a significant correlation with the observed GWL. It was an acceptable correlation coefficient for the modeling. However, the observed GWL data from March to June 2019 showed the strange fluctuation, and there were some missing data. This condition could be because of the disturbance on the data logger equipment in the site area.

### 3.2. Modeling using two-months, three-months, and six-months data

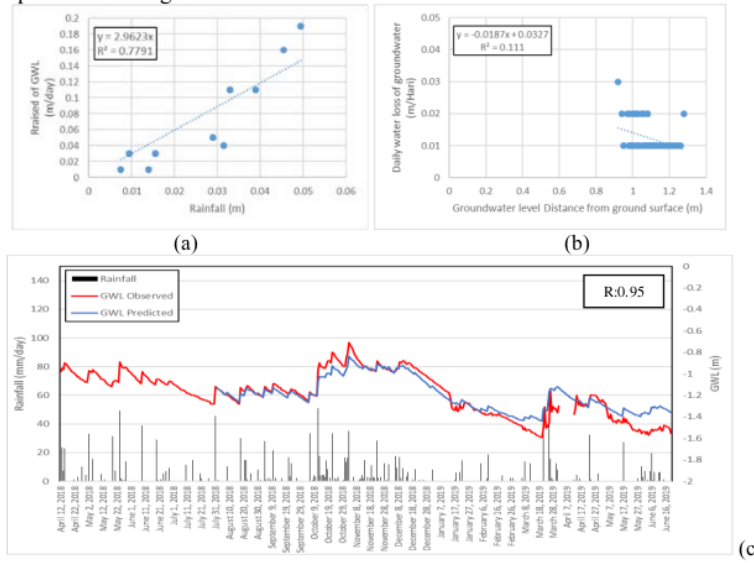
The regression analysis of  $dW_{rain}$  and  $dW_{loss}$  using two-month data from May to June 2018 is presented in Fig. 5a and Fig. 5b respectively. With one-month additional data (three rainfall additional data), the determination coefficients of the  $dW_{rain}$  and  $dW_{loss}$  regression analysis became 0.7446 and 0.1071 respectively. Although the determination coefficients using two-month data regression analysis were smaller than that of one-month data analysis, the correlation coefficient between the predicted GWL and observed GWL was stronger which was about 0.89 (Fig. 5c).



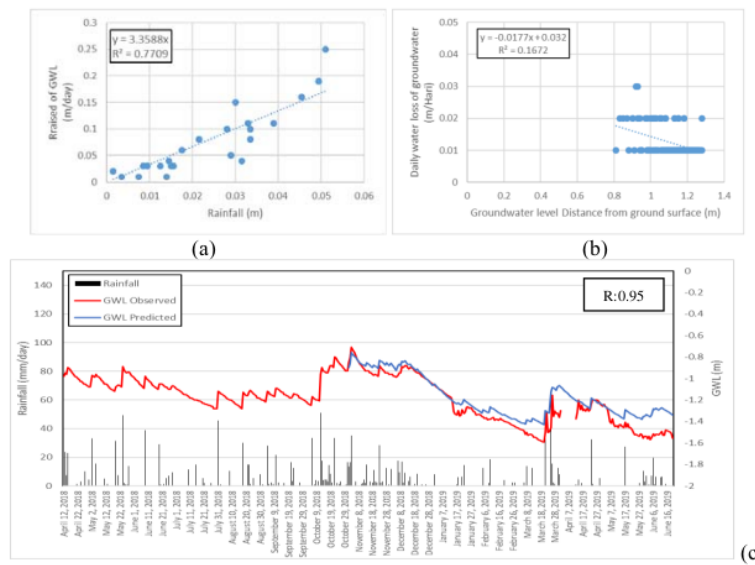
**Figure 5.** The modeling process of  $dW_{rain}$  (a),  $dW_{loss}$  (b) and comparison of predicted GWL with observed GWL (c) using two-months data (May-June 2018)

The regression analysis of  $dW_{rain}$  and  $dW_{loss}$  using three-month data from May to July 2018 yielded the determination coefficients of 0.7791 and 0.111 respectively as presented in Fig. 6a and Fig. 6c. This determination coefficient of  $dW_{rain}$  was higher than that of one-month and two-months data modeling. However, the determination coefficient of  $dW_{loss}$  was lower than that of one-month data modeling and was higher than that of two-months data modeling. The prediction of GWL using three-months data modeling represented a very strong relationship with the observed GWL data with the correlation coefficient of 0.95 as presented in Fig. 5c. The prediction of GWL using six-months data modeling also represented a very strong relationship with the observed GWL data with the correlation coefficient of 0.95 as presented in Fig. 7c. In the regression modeling process, the determination coefficient of  $dW_{loss}$  was the highest with was about 0.1672 as presented in Fig. 7b. However, the determination coefficient of  $dW_{rain}$  was slightly lower than that of three-months data modeling and was higher than that of one-month and

two-months data modeling. The determination coefficient of  $dW_{\text{rain}}$  using six-months data modeling was about 0.7709 as presented in Fig. 7a.



**Figure 6.** The modeling process of  $dW_{\text{rain}}$  (a),  $dW_{\text{loss}}$  (b) and comparison of predicted GWL with observed GWL (c) using tree-months data (May-July)



**Figure 7.** The modeling process of  $dW_{\text{rain}}$  (a),  $dW_{\text{loss}}$  (b) and comparison of predicted GWL with observed GWL (c) using six-months data (May-October)



From the above discussion, it was clear that the more data used for modeling, the better of the GWL prediction results were obtained. It was because the model could represent the response of GWL fluctuation in a wide range of hydrological conditions in both dry and rainy season very well. However, using one-month data only for modeling was sufficient for GWL prediction with acceptable results, if there was enough number of the rainfall event and the GWL fluctuation could represent well the response as the impact of the rainfall. This information is useful if there is a limited number of data for the prediction of GWL in the future.

Judging from all observed and predicted GWL that the GWL is always in a lower position than 0.4 m depth in Dompas village, this area is always in the high risk of peat fire throughout the year. To mitigate this condition, it is very important to manage water resources properly by a rewetting approach using canal blocking to raised GWL in the peatland [14].

#### 4. Conclusion

This research developed a hydrological model using regression analysis that can be used to predict GWL in the peatland so that it can be used to predict the level of risk of peat fires as a basis for early warning. The GWL is a key parameter for assessing the level of fire risk in the peatland. Regression analysis was carried out using four data length scenarios, such as one-month, two-months, three-months, and six-months to find out which time period could represent hydrological conditions in the field. The results showed that the regression analysis with a data length of three-months and six-months represented the best results of the GWL prediction with a correlation coefficient value of 0.95. However, the prediction of GWL using regression analysis with data lengths of one-month and two-months represented a reasonable prediction result with a correlation coefficient value of 0.86 and 0.89 respectively. This means that the GWL can be predicted even only use one-month data if the response of GWL because of rainfall represents the hydrological process in the peatland along the year very well.

Judging from all observed and predicted GWL that the GWL is always in a lower position than 0.4 m depth in Dompas village, this area is always in the high risk of peat fire throughout the year. To mitigate this condition, it is very important to manage water resources properly by a rewetting approach using canal blocking to raised GWL in the peatland.

#### 5. Acknowledgement

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