GROUNDWATER LEVEL ESTIMATION MODEL ON PEATLANDS USING SAR SENTINEL-1 DATA IN PART OF RIAU, INDONESIA

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Abstract. The character of peatlands has the ability to store large amounts of water, but the surface of the peatlands dries quickly and easy to burn during the dry season. Research aims to build a model to estimate groundwater level of peatland. Statistical analysis of Karl Pearson Product Moment correlation test was used to determine the relationship between the back scatter values and the Surface Soil Moisture (SSM) values from the Sentinel-1 SAR data processing with the groundwater level values measured using the Sipalaga instrument. Regression analysis was used to determine the model that could be used to estimate the groundwater level of peatlands in the study area based on the results of Sentinel-1 SAR data processing. The results showed that the Sentinel-1 SAR data with the Sigma_0 format in decibel (db) units with VV polarization had the highest correlation value with the groundwater level data of peatlands measured using the Sipalaga instrument, with a value of r -0.648 (moderate correlation). Model to estimate water level of peatlands was Y = -101.629 + (-7.414 x), where 'Y' was the groundwater level of peatlands in the study area and 'x' was the Sentinel-1 SAR data with Sigma_0 format in decibel (db) units with VV polarization. The spatial and temporal patterns of peatlands groundwater level in the study area from Sentinel-1 SAR data showed peatlands that to survive at a water level <40 cm was in the area around of the Rokan River and also in plantation areas, especially Acacia plantations, where canals were made to irrigate and land management.

Keywords: *Peatlands, Groundwater Level, Sentinel-1*

1 INTRODUCTION

Sumatra and Kalimantan Islands regions of Indonesia have quite extensive peatlands, which are around 75% of the total peatlands area in Indonesia (Ritung, 2011). The nature of peatlands able to store large amounts of water but the surface of peatlands dries up quickly and burns easily during the dry season (Wosten, 2008). Peatland fires are influenced by several factors, both weather and peatland characteristics, includes peat moisture, peat decomposition, water level, and rainfall. The higher the water content of peatlands, the lower the rate of burning (Saharjo and Syaufina, 2015).

It is very important to control forest and peatland fires and is prioritized in terms of prevention (BNPB, 2014). According to PP. 71 of 2014 in conjunction with PP No.57 of 2016 concerning the Protection and Management of Peat

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Ecosystems, the criteria for a peatlands ecosystem are declared damaged if the groundwater level is more than 0.40 meters below the surface of the peatlands. The determined groundwater level has a close relationship with occurrence of fire, where fire events are mainly affected by the El-Nino and groundwater level drops below 0.30 (Putra, 2011).

Measuring wetness level of peatland ecosystem has been more focused on the amount of water in the soil, for example by using a groundwater level instrument (Ketridge et al., 2015). The groundwater level instruments have good data quality, where the groundwater level data are quantitative. However, because the measurement instruments is carried out at a certain point, it has spatial shortcomings. Problems in the placement of the instrument location, data delivery system, and maintenance costs also continue to be a problem until now (Sulaiman, 2017). Remote sensing technology can be the answer to these limitations, especially remote sensing with active or radar systems. The Synthetic Aperture Radar (SAR) Sentinel-1 data belonging to the ESA (European Space Agency) is an active system of remote sensing data, one of which is used in land monitoring, including monitoring the wetness level of peatlands (Marschallinger, B., 2019).

Through this research, it was found that an approach could obtain not only qualitatively, but also quantitatively periodic monitoring the groundwater level of peatlands in Indonesia using remote sensing data from SAR Sentinel-1. So that the monitoring system for groundwater level for forest and land fire prevention could complement each other between the Sipalaga instrument (BRG) and also from remote sensing image data.

2 MATERIALS AND METHODOLOGY

2.1 Location and Data

The research area is located at 000 25'00 "to 010 30'00" North and 1010 10'00 "to 1020 30'00" East which part of the peatland area in the Riau Province, Indonesia. The existence of peatlands is dominantly located in the eastern coastal area with various depths ranging from 0.5 m to more than 4 m. The mostly peatland formed by the accumulation of organic matter with an area of approximately ± 5 million ha, which is generally the type of Hemists and Saprists peat. Spatially, the distribution of peatlands and the study area is represented in Figure 2-1.

2.2 SAR Sentinel-1 Data Processing

SAR Sentinel-1 image processing in this study consisted of image radiometric correction, speckle reduction, geometric correction, subset or mask image and data processing using the Surface Soil Moisture (SSM) algorithm. Data processing until the subset or mask image was carried out on 11 Sentinel-1 data with different recording dates for Vertical Horizontal (VH) and Vertical Vertical (VV) polarization. Meanwhile, Surface Soil Moisture (SSM) processing was carried out for selected data, which represented very wet and very dry conditions also one data that represented a certain time.

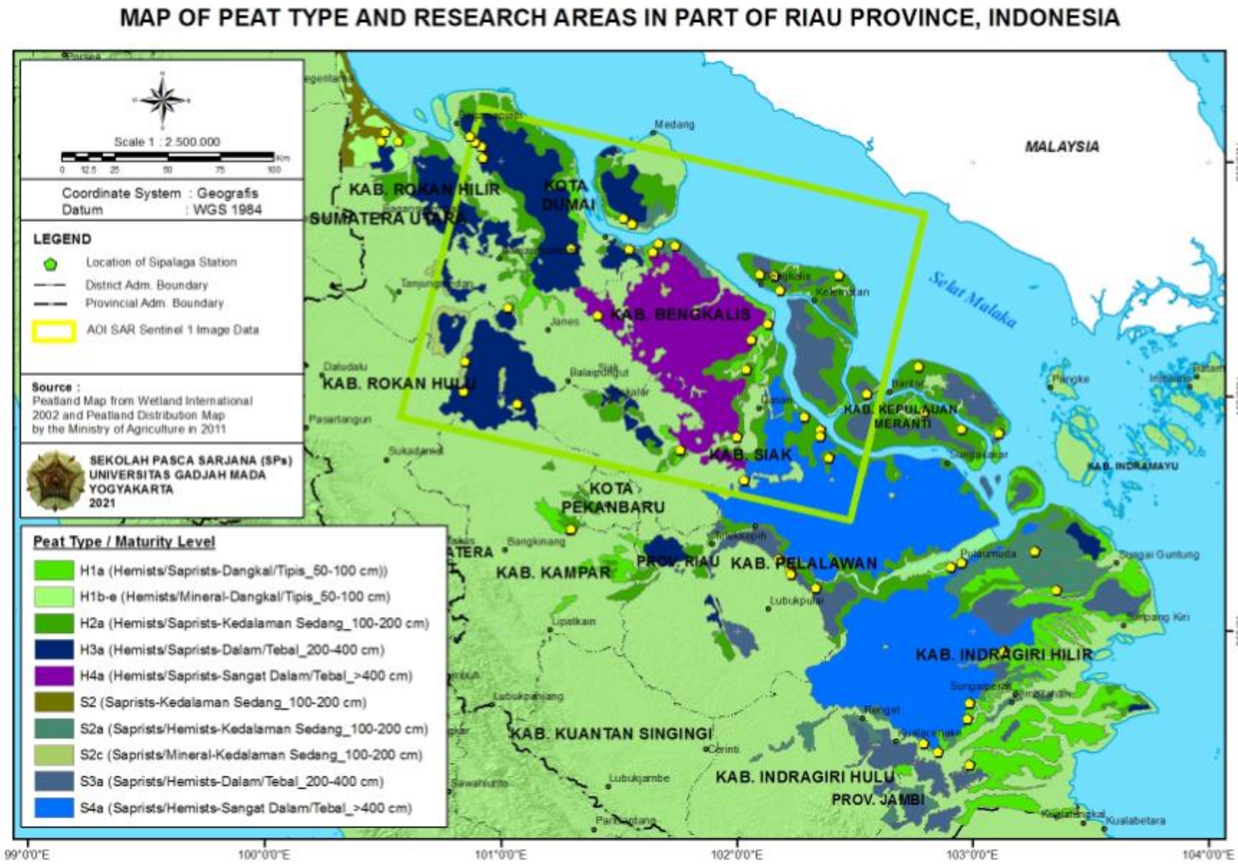

Figure 2-1. Map of Peat Types and Research Study Areas in Parts of Riau Province, Indonesia

Table 2-1. Materials, data used, and the sources of data collection.

No	Materials and Data	Sources of Data
1	Sentinel-1 SAR Data parts of Riau Province, recorded on November 19 2018, December 13 2018, January 30 2019, May 30 2019, July 17 2019, August 22 2019, and December 8 2019, January 13 2020, May 12 2020, August 04 2020, and December 02 2020	European Space Agency, ESA (https://scihub. copernicus.eu/dhus/#/home.)
2	DEMNAS Data the part of Riau Province	Geospatial Information Agency (BIG)
3	Landsat 8 imagery acquired March 15, 2019	United States Geological Survey, USGS (https://earth explorer.usgs.gov/)
4	Peatland Maps 2002 and 2011	Ministry of Agriculture and Wetland International
5	Landuse Data 2017 and 2019	Geospatial Information Agency & Ministry of Forestry and Environment, also Google Street View
6	Recording data of soil moisture, Groundwater level (GWL), and rainfall on peatlands area from the Sipalaga instrument for the period of November 2018 - December 2020	Peat Restoration Agency (BRG).

The Surface Soil Moisture (SSM) algorithm was represented as follows:

$$SSM = \frac{\sigma^0_{(40,t)} - \sigma^0_{dry(40)}}{\sigma^0_{wet(40)} - \sigma^0_{dry(40)}} [\%] \qquad (2\text{-}1)$$

explanation:

SSM	=	Surface Soil Moisture (%)
$\sigma^0_{(40,t)}$	=	Backscattering value at reference angle 40° at certain time (t)
$\sigma^0_{dry(40)}$	=	Backscattering value at a reference angle of 40° under very dry land conditions
$\sigma^0_{wet(40)}$	=	Backscattering value at a reference angle of 40° under very wet conditions

2.3 Statistical Analysis

Statistical analysis was used to determine the optimal model to use for monitoring the groundwater level of peatlands in the study area using Sentinel-1 data. The method used was the Karl Pearson Product Moment correlation test method, where the image pixel value that represented the back scatter value and the SSM value from Sentinel-1 data processing were correlated with the groundwater level data of peatlands measured by the Sipalaga instrument owned by Peat Restoration Agency (BRG). Meanwhile, the linear regression method was conducted to determine the best model to estimat groundwater level of peatlands based on the results of Sentinel-1 data processing.

The Karl Pearson Product Moment correlation test method was represented as follows:

$$r = \frac{N\sum xy - (\sum x)(\sum y)}{\sqrt{\left[N\sum x^2 - (\sum x)^2\right] x \left[N\sum y^2 - (\sum y)^2\right]}} \qquad (2\text{-}2)$$

explanation:

r	=	Coefficient of correlation
x	=	Independent variable (Backscatter Sigma_0_db (VH, VV) and SSM value (VV, VH)
y	=	Dependent variable (Groundwater level)

To interpret the closeness of the relationship between variables, the following criteria were used as represented in Table 2:

Table 2-1: Classification of the level of the relationship based on the value of the correlation coefficient (Guilford dan Fruchter, 1978)

No	Correlation Coefficient Interval	Relationship Level
1	0.00 – 0.199	Very low
2	0.20 – 0.399	Low
3	0.40 – 0.699	Moderate
4	0.70 – 0.899	Strong
5	0.90 – 1.000	Very Strong

The linear regression model used in this study with the following equation :

$$y = a + bx \qquad (2\text{-}3)$$

explanation:

y	=	Dependent variable (Ground-water level)
x	=	Independent variable (Backscatter Sigma_0_db (VH, VV) or SSM value (VV, VH)
a	=	Value of y if x = 0 (constant)
b	=	Regression coefficient

3 RESULTS AND DISCUSSION

3.1 Peatland Groundwater Level Measurement

Peatland groundwater level data used in this study was direct measurement data using the Sipalaga instrument belonging to the Peat Restoration Agency (BRG) in parts of Riau Province during the period November 14, 2018 to December 02, 2020. Description of the Sipalaga instrument installed in the peatland area along with sensors The gauges are visualized in Figure 3-1. In the Sipalaga instrument, at least there are sensors to measure rainfall, soil moisture, and water level of peatlands. The total data of the Sipalaga instrument used in this study amounted to 20 locations scattered in the peatland area in the study area. In detail, the location of the distribution of the Sipalaga instrument belonging to the Peatland Restoration Agency (BRG) was represented in Table 3-1.

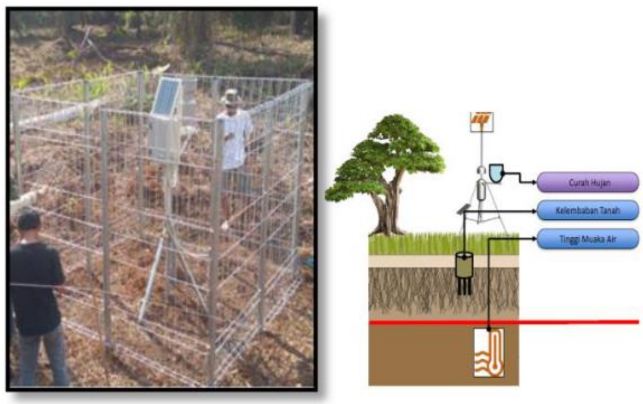

Figure 3-1: BRG's Peatland Water Monitoring System (Sipalaga) instrument that measures groundwater level, soil moisture and rainfall data for Sumatra and Kalimantan islands

Table 3-1: Location distribution of BRG's Sipalaga Instruments in the study area

No	Station Name	Coordinate		Districts
		Lat	Lon	
1	Pedekik	1.51	102.09	Bengkalis
2	Penampi	1.45	102.18	Bengkalis
3	Bantan T.	1.51	102.15	Bengkalis
4	Muntai	1.51	102.42	Bengkalis
5	Batu P.	1.75	101.52	Bengkalis
6	Terkul	1.73	101.55	Bengkalis
7	Sumber J.	1.24	102.06	Bengkalis
8	Tasik S.B.	1.34	101.41	Bengkalis
9	Sontang 1	0.99	100.83	Rohul
10	Sontang 2	1.02	100.84	Rohul
11	Labuhan T.B.	2.06	100.91	Rohil
12	Labuhan T.B. 2	2.06	100.88	Rohil
13	Labuhan T. K.	2.01	100.92	Rohil
14	Rantau K.	1.37	101.03	Rohil
15	Kampung R.	0.82	102.00	Siak
16	Penyengat 2	0.85	102.35	Siak
17	Buatan I	0.77	101.77	Siak
18	Sam Sam	0.96	101.07	Siak
19	Pelintung	1.61	101.64	Dumai
20	Teluk M.	1.62	101.54	Dumai

3.2 SAR Sentinel-1 Image Processing

SAR Sentinel-1 image processing consists of at least five stages, including radiometric correction, speckle reduction, geometric correction, subset or mask image and data processing using the Surface Soil Moisture (SSM) algorithm. Data processing until the subset or image masking process was carried out on 11 Sentinel-1 SAR data with different recording dates for VH and VV polarization respectively. In the radiometric correction process, the Digital Number (DN) value was converted into a backscatter value in the Sigma_0 format in decibels (db). The speckle filtering process was needed to remove spots that look like salt or paper on Sentinel-1 images.

Geometric correction had been conducted to geocode the image by correcting the geometric distortion using DEMNAS data with a spatial resolution of 10 meters, and projecting the data to a geographic coordinate system using the WGS84 datum. After the data was geometrically corrected, then a subset or mask image was carried out using the reference of the peatland area in the study area. After all these steps were carried out, the selected data was processed using the Surface Soil Moisture (SSM) algorithm. For example, the complete initial processing of the Sentinel-1 SAR data was represented in Figure 3-2.

Sentinel-1 Image data processing using the Surface Soil Moisture (SSM) algorithm was carried out for Sentinel-1 data on May 30, 2019, this data processing was carried out to determine the correlation of the SSM value from Sentinel-1 data processing to the groundwater level values.

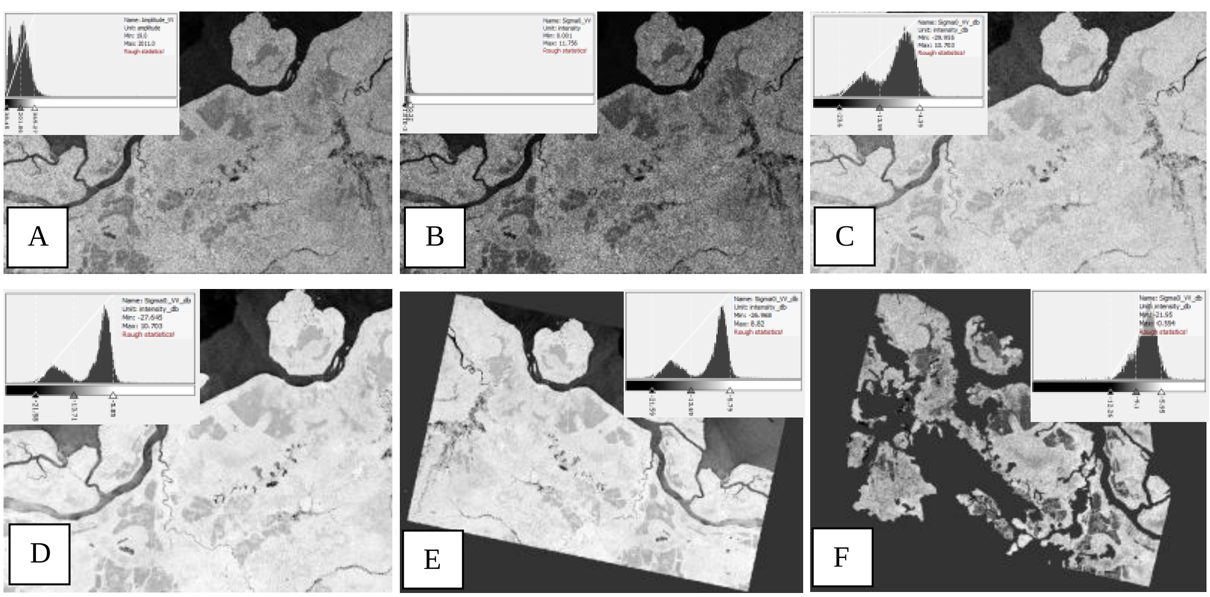

Figure 3-2: Pre-processing of SAR Sentinel-1 data, (A). The original format data that values was digital number, (B). Image after the radiometric calibration in the sigma_0 format, (C). Image after the pixel value was converted to desibel (db), (D). Image after speckle filtering, (E). Image after geometric correction, (F). Image after subset or mask image

Groundwater Level (GWL) of peatlands in the study area measured using the Sipalaga instrument. Referring to historical rainfall data in the study area, the Sentinel-1 data used as a reference when conditions are very wet was the recorded on December 13, 2018, while the Sentinel-1 data used as a reference for very dry conditions was the recorded on August 22, 2019. The processing of Surface Soil Moisture in this study was carried out for the Sentinel-1 data, both data with VH and VV polarization.

Beside carrying out the data from Surface Soil Moisture (SSM) processing, statistical analysis was also carried out on Sentinel-1 data recorded on May 30, 2019 which represented the actual backscatter value of objects on the earth's surface in the Sigma_0 data format with decibel (db) units both with VH and VH polarization. This was done in order to obtain the best methods and models in the effort to estimate the groundwater level of peatlands from the results of Sentinel-1 data processing. Based on this, the analysis of the prediction of groundwater level (GWL), was carried out on four data from Sentinel-1 data processing on May 30, 2019, as represented in Figure 3-3.

Comparison of the pixel value of the SAR Sentinel-1 image recorded on May 30, 2019 at the location of the Sipalaga station, between the image that represented the back scatter value of the Sigma_0 format in decibels and the image produced by Surface Soil Moisture (SSM) processing both with VV and VH polarization, with Groundwater level results from direct measurements using the Sipalaga instrument were represented in Table 3-2.

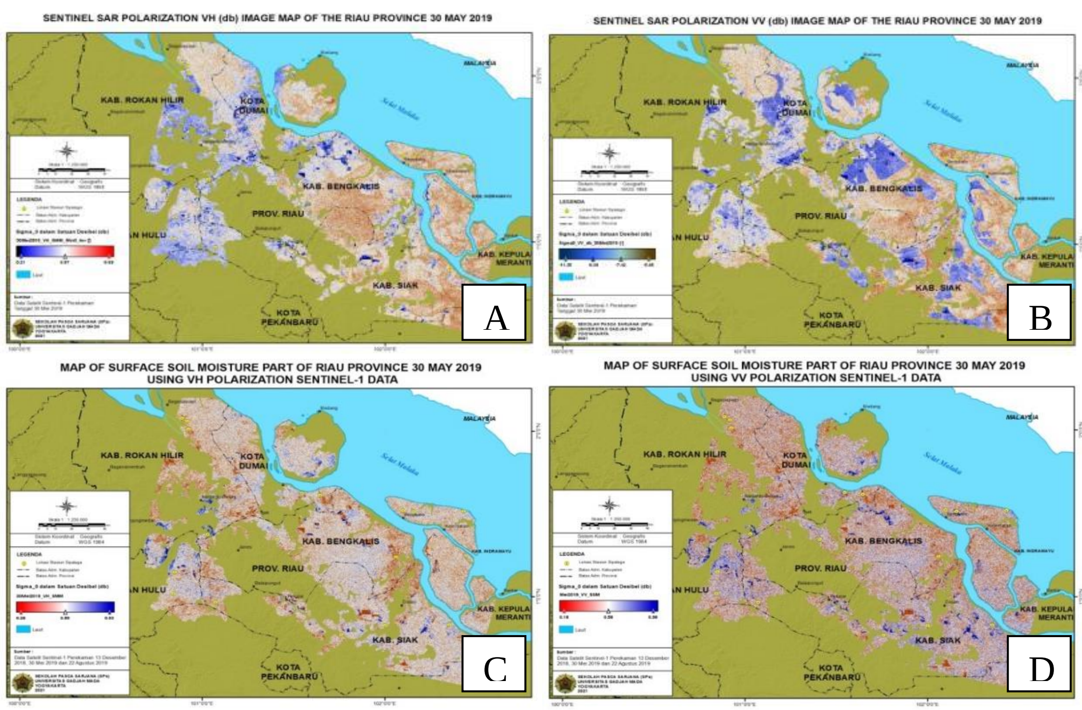

Figure 3-3: Image of SAR Sentinel-1 May 30, 2019: (A). polarization of VH Sigma_0 format in decibels (db), (B). polarization VV Sigma_0 format in decibels (db), (C). Polarization of VH as a result of Surface Soil Moisture (SSM) processing, and (D). Polarization of VV as a result of Surface Soil Moisture (SSM) processing

Table 3-2: The comparison of the back scatter value (sigma_0_db) and the results of the processing using Surface Soil Moisture, both with VV and VH polarization with Groundwater level (GWL) measured using the Sipalaga instrument for May 30, 2019

No	Sipalaga Station	GWL	*Sigma_0 _db(VH)*	*Sigma_0 _db (VV)*	SSM (VH)	SSM (VV)
1	Pedekik, Kab. Bengkalis	-65.800	-13.106	-6.580	0.497	0.614
2	Penampi, Kab. Bengkalis	-46.400	-14.781	-6.974	0.695	0.473
3	Bantan Tua, Kab. Bengkalis	-51.500	-12.552	-7.440	0.716	0.647
4	Muntai, Kab. Bengkalis	-41.800	-11.787	-7.644	0.657	0.591
5	Batu Panjang, Kab. Bengkalis	-42.000	-13.681	-6.751	0.501	0.597
6	Terkul, Kab. Bengkalis	-54.400	-14.725	-8.919	0.704	0.530
7	Sumber Jaya, Kab. Bengkalis	-46.400	-14.053	-8.622	0.539	0.681
8	Tasik Serai Barat, Kab. Bengkalis	-41.700	-13.207	-5.150	0.726	0.625
9	Sontang 1, Kab. Rokan Hulu	-47.300	-16.085	-7.645	0.619	0.433
10	Sontang 2, Kab. Rokan Hulu	-67.200	-14.162	-4.830	0.523	0.767
11	Labuhan Tangga Besar, Kab. Rokan Hilir	-62.000	-13.607	-6.657	0.480	0.449
12	Labuhan Tangga Besar 2, Kab. Rokan Hilir	-16.800	-17.080	-8.498	0.536	0.819
13	Labuhan Tangga Kecil, Kab. Rokan Hilir	-18.000	-14.702	-9.652	0.664	0.743
14	Rantau Kopar, Kab. Rokan Hilir	-44.300	-16.611	-6.162	0.708	0.727
15	Kampung Rempak, Kab. Siak	-66.600	-14.858	-6.510	0.544	0.591
16	Penyengat 2, Kab. Siak	-34.100	-16.035	-7.922	0.660	0.701
17	Buatan I, Kab. Siak	-67.600	-14.341	-5.812	0.585	0.825
18	Sam Sam, Kab. Siak	-44.200	-14.702	-7.241	0.588	0.669
19	Pelintung, Kota Dumai	-59.100	-13.011	-6.989	0.614	0.596
20	Teluk Makmur, Kota Dumai	-34.400	-15.831	-9.514	0.683	0.739

3.3 Vegetation Density Data Processing

The data processing of vegetation density in this study used the NDVI transformation model, while the data used was multi-temporal data from Landsat 8 imagery acquired on March 15, 2019 and October 18, 2020. The NDVI Transformation Model is a transformation model that utilizes the band ratio of the near infrared channel and the red channel, respectively band 5 and band 4 in the Landsat 8 image data.

The results of the processing of vegetation density data were used as the basis for statistical analysis of the level of correlation between the back scatter value and the SSM value of the Sentinel-1 SAR image acquired on January 30, 2019, with the groundwater level of peatlands in the study area as a result of direct measurements in the field by Sipalaga instruments.

The results of processing the Vegetation Density Map in peatland areas in parts of Riau Province were represented in Figure 3-4. Meanwhile, the existence of Sipalaga Station at each vegetation density level and the percentage area of each vegetation density class on the peatland was represented in detail in Table 3-3.

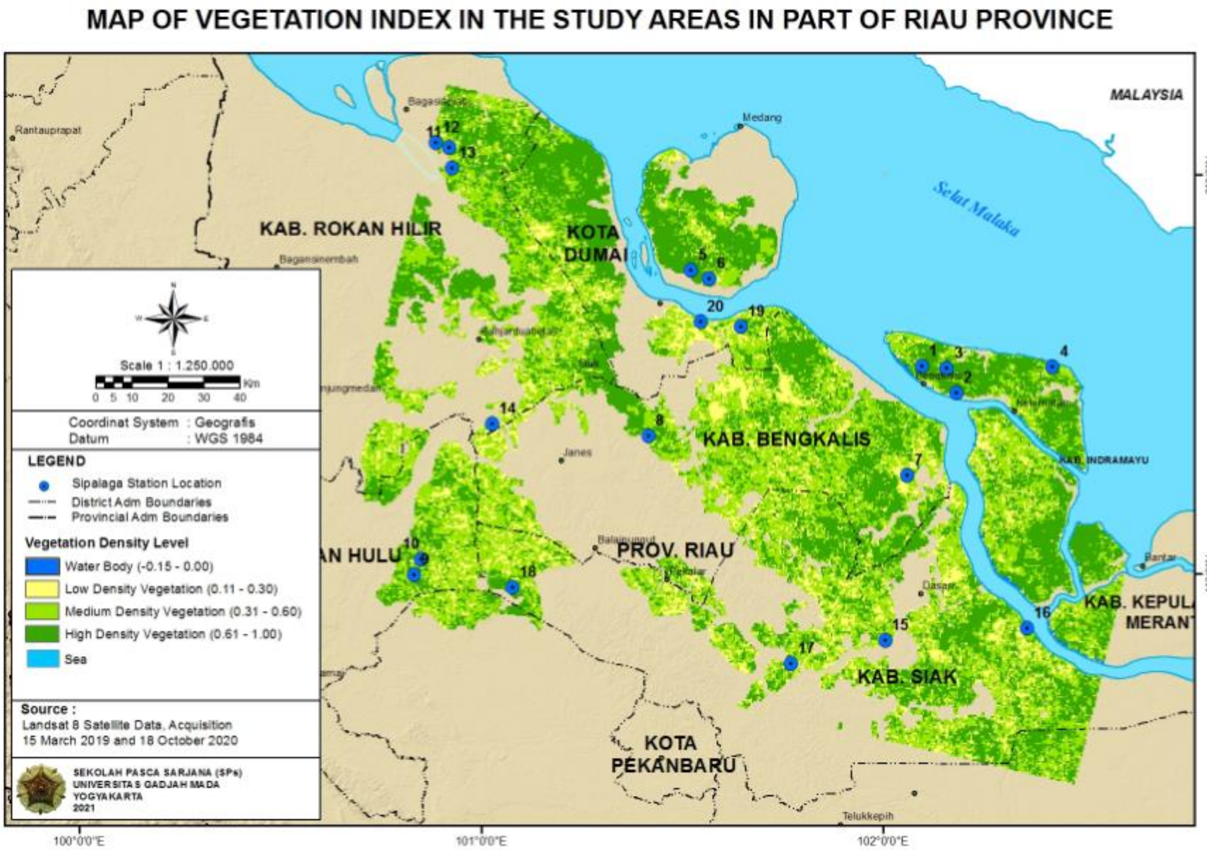

Figure 3-4: Vegetation Density Map in parts of Riau Province in 2019

Table 3-3: The existence of Sipalaga station and the percentage area of vegetation Index in the peatland area of the study area

No	Sipalaga Instrument	Vegetation Index	Km²	%
1	7, 14, 15, 16, 17, 19, 20	Low	2.547,82	16,27
2	4, 6, 8, 9, 10, 11, 12, 13	Medium	6.651,15	42,47
3	1, 2, 3, 5, 18	High	6.397,84	40,86
4	-	Body of Water	61,12	0,39
		TOTAL	15.657,95	100%

3.4 Statistical Analysis (Correlation Regression Test)

The correlation test was carried out to determine the strength of the relationship between the back scatter value in the Sigma_0 format in decibels (db) as well as the Surface Soil Moisture (SSM) value from the processing of SAR Sentinel-1 data with groundwater level of peatlands measured in the field by BRG's Sipalaga instrument. The correlation test had not only been carried out on the entire data, but also on the data each level of vegetation density in the study area, so that it was expected to obtain optimal model criteria to estimate the groundwater level of peatlands from the Sentinel-1 SAR data.

The results of the correlation test of peatland groundwater level with data from Sentinel-1 image processing were represented in Table 3-4. Based on the test results, it could be known that the highest correlation between the peatlands groundwater level in the study area was the Sentinel-1 data format Sigma_0 in decibels (db) unit with VV polarization, with an r value -0.648 (moderate correlation). The highest correlation value for this data was in areas with low vegetation cover with a correlation coefficient of -0.729 (strong correlation), while in areas with moderate vegetation cover the correlation value was - 0.647 (moderate correlation) and in areas with high vegetation cover it had correlation value of -0.397 (low correlation).

The results of the correlation test were then used as the basis for the regression test process. Where the regression test was carried out to obtain a model of the relationship between the groundwater level of peatlands and the data from the SAR Sentinel-1 image processing in the form of Sigma_0 data in decibels (db) units with VV polarization. The equation model generated from the regression test could later be used to estimate the groundwater level of peatlands in the study area.

The summary model and the coefficients from the regression test represented in Table 3-5. Based on the regression test, it was known that the constant value (a) in the linear regression model was -101.629 and the regression coefficient (b) was -7.414, with a value of r 0.648 and r2 0.42. The value of r and r2 could potentially be increased by adding groundwater level measurement points in the field using the Sipalaga instrument or other instruments, used as data input in statistical analysis of correlation and regression tests.

Table 3-4: The results of the Groundwater Level (GWL) correlation test with the results of Sentinel-1 data processing on May 30, 2019

No	Groundwater Level (Dependen Variable)	Independen Variable (X)							
		Sigma_0 _db (VH)		***Sigma_0 _db (VV)***		**SSM (VH)**		**SSM (VV)**	
		r	**Sig (5%)**	**r**	**Sig (5%)**	**r**	**Sig (5%)**	**r**	**Sig (5%)**
1	All station data	-0.428	0.06	-0.648	0.002	0.339	0.144	0.295	0.207
2	Station- low vegetation index	-0.622	0.136	-0.729	0.063	0.659	0.107	0.178	0.702
3	Station- medium vegetation index	-0.387	0.344	-0.625	0.097	0.264	0.527	0.516	0.191
4	Station- hight vegetation index	-0.555	0.332	-0.397	0.509	0.236	0.702	-0.128	0.837

Table 3-5: The results of the groundwater level regression test with a back scatter value of Sigma_0 format in decibels (db) units with VV polarization

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.648[a]	.420	.388	11.61064

Coefficients[a]						
Model		*Unstandardized Coefficients*		*Standardized Coefficients*	t	Sig.
		B	*Std. Error*	Beta		
1	*(Constant)*	-101.629	15.193		-6.689	.000
	Sigma0_db_VV	-7.414	2.052	-.648	-3.611	.002

a. Dependent Variable: Groundwater Level

b. Predictors: (Constant), Sigma0_db_VV

Based on the regression test, an equation model that could be used to estimate the groundwater level of peatlands in the study area based on the SAR Sentinel-1 data Sigma_0 format in desibel (db) units with VV polarization, as follows:

$$Y = -101.629 + (-7.414\ x) \qquad (3\text{-}1)$$

explanation:

Y = Peat water level

x = SAR Sentinel-1 image sigma_0 format in decibels (db) units with VV polarization

The groundwater level prediction model generated from the regression analysis was then used to process Sentinel-1 data for the period November 19, 2018 to December 02, 2020. Based on the processing results as represented in Figure 3-5, it was known that Sentinel-1 data could be used to predict and monitor peatlands groundwater level conditions. This could be seen from the fluctuation in groundwater conditions at the peatland level in the study area during the period of November 19, 2018 to December 02, 2020. In general, the peatland area tended to be dominant in wet conditions at the end and beginning of the year where this period was the peak of the rainy season, while the conditions peatlands were generally dry, starting around May and peaking around July / August.

From the groundwater level prediction model for peatlands during the period of November 19, 2018 to December 02, 2020 it could also be seen that peatlands that tended to persist at a groundwater level <40 cm were around the Rokan River and also in plantation areas, especially Acacia plantations, which are made canals with functions for land management and irrigating plantation crops. Whereas areas that have significant fluctuation in GWL each year are in parts of Rokan Hilir Regency and Dumai City (northwestern part of the study area) and parts of Bengkalis Regency (middle part of the study area), which are mostly still natural with land cover mixed with scrub and swamp forest.

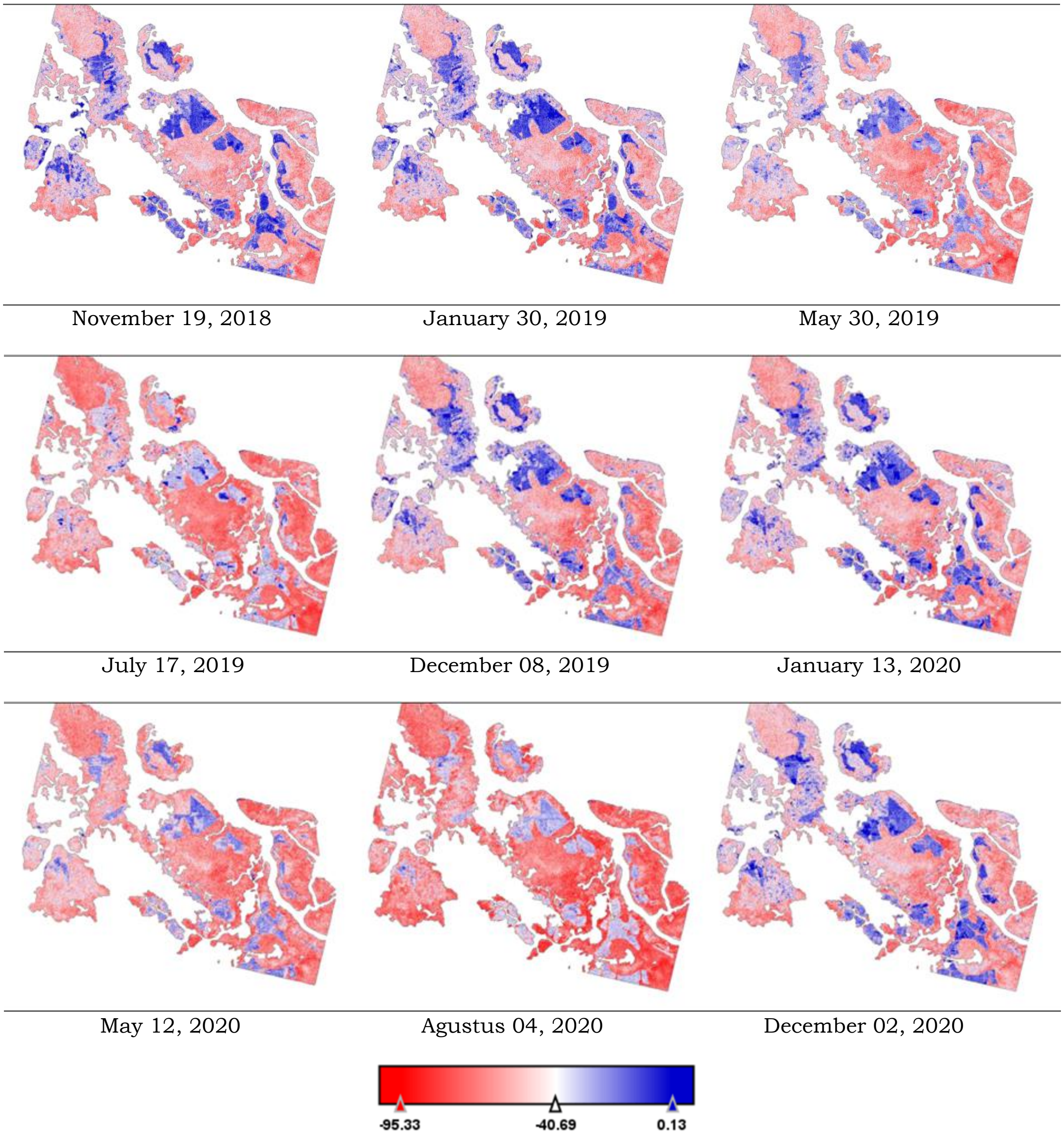

Figure 3-5: Spatial and temporal distribution of peatland water level estimates based on Sentinel-1 SAR data for the period of November 19, 2018 to December 02, 2020 in parts of Riau Province

4 CONCLUSION

Sentinel-1 SAR data with the Sigma_0 format in decibel (db) units with VV polarization had the highest correlation value with peatlands groundwater level data measured using the Sipalaga instrument, with a value of r -0.648 (moderate correlation). Based on the spatial and temporal groundwater level patterns of the peatland in the study area from SAR Sentinel-1 data, it could be seen that peatlands that tend to survive at a groundwater level of <40 cm are in around the Rokan River and also in plantation areas, especially Acacia plantations, where canals made for land management and irrigating plantation crops.

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AUTHOR CONTRIBUTIONS

Ardila Yananto (conceptualisation, methodology, data processing, investigation, analysis, validation, visualisation, writing of the original draft, review writing and editing); Junun Sartohadi (conceptualisation, supervision and review writing); Hero Marhaento (conceptualisation, supervision and review writing); and Awaluddin (conceptualisation, methodology and supervision).

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