Vol. 23 No. 1 (Januari 2022) 110 – 117
e-ISSN 2548-6101 p-ISSN 1411-318X

Jurnal Teknologi Lingkungan

Journal Homepage: ejurnal.bppt.go.id/index.php/JTL

Wetlands Delineation with Various Land Covers Using SAR Sentinel-1A Surface Backscatter Ratio

Delineasi Lahan Basah dengan Beragam Tutupan Lahan Menggunakan SAR Sentinel-1A Surface Backscatter Ratio

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INFORMASI ARTIKEL

Histori artikel:
Diterima 25 Oktober 2021
Disetujui 12 Januari 2022
Diterbitkan 23 Januari 2022

Kata Kunci:
SAR Sentinel-1A
Lahan Basah
Backscatter
Program Konservasi
Keberlanjutan

ABSTRAK

Wilayah Kabupaten Ogan Komering Ilir (OKI) yang didominasi lahan basah memerlukan perencanaan tata guna lahan yang tepat untuk mendukung program kesejahteraan dan pelestarian lingkungan. Program tersebut perlu disusun berdasarkan data lahan basah yang tepat dalam penetapan tata guna lahan. Artikel ini mengeksplorasi pemanfaatan data satelit Synthetic Aperture Radar (SAR) Sentinel-1A untuk mengidentifikasi area lahan basah dengan berbagai tutupan lahan untuk menyediakan peta lahan basah skala menengah secara cepat. Peta kelembaban tanah diambil dari platform SEPAL untuk memantau pola kelembaban tanah sepanjang 2015–2017. Profil hamburan balik polarisasi VV (δVV) dan polarisasi VH (δVH) dianalisis untuk data sentinel-1 dari tahun 2015 hingga 2018. Rasio antara nilai VV dan VH (δVV/δVH) serta tekstur VV dan VH digunakan sebagai acuan untuk menentukan lahan basah; ditentukan pada analisis eksperimental profil kelembaban tanah, konstanta dielektrik, dan nilai koefisien hamburan balik dari penelitian lain. Rasio VH/δVV yang rendah (berkisar antara 1,3 dan 1,6) terletak di bagian utara Kabupaten OKI dan sebagian besar ditutupi oleh tanaman akasia. Estimasi ini sejalan dengan peta Kesatuan Hidrologis Gambut dan data validasi berdasarkan ground check lapangan. Secara keseluruhan, rasio δVH/δVV tahunan bernilai relatif sama, dengan nilai variasi yang kecil. Studi ini menemukan kemampuan Sentinel-1A untuk keperluan klasifikasi tipe vegetasi lahan basah yang akurat, terutama lahan basah bervegetasi herba atau semak, tetapi tidak untuk lahan basah bervegetasi tinggi

ARTICLE INFO

Article history:
Received 25 October 2021
Accepted 12 January 2022
Published 23 January 2022

Keywords:
SAR Sentinel-1A
Wetland
Backscatter
Conservation Programs
Sustainability

ABSTRACT

Ogan Komering Ilir (OKI) Regency area, dominated by wetlands, requires appropriate land use planning to support welfare and environmental conservation programs. This article explores the utilization of Synthetic Aperture Radar (SAR) Sentinel-1A satellite data to identify wetland areas with various land covers to provide a medium scale wetland map quickly. The soil moisture maps were captured from the SEPAL platform to monitor soil moisture patterns throughout 2015–2017. The backscattering profiles of VV (δVV) polarization and VH polarization (δVH) were then analyzed for data sentinel-1 from 2015 to 2018. The ratio between VV and VH (δVV/δVH) values and textures of VV and VH is used as a reference to determine the wetland area; determined on an experimental analysis of soil moisture profile, dielectric constants, and backscattering coefficient values from other studies. The low δVH/δVV ratio (ranges between 1.3 and 1.6) is located in the northern OKI regency and is mainly covered by acacia plantations. These estimations align with the Peat Hydrology Unit maps and ground check as validation data. Overall, the δVH/δVV ratio is relatively the same yearly, with a small variation value. This study found the capability of Sentinel-1 for the accurate classification of wetland vegetation types, primarily herbaceous or shrubby vegetated wetlands, but not for high-vegetated wetlands.

1. INTRODUCTION

1.1 Background

Ogan Komering Ilir (OKI) Regency is located in a tropical area in the southeastern part of Sumatra Island, Indonesia. Most of the OKI Regency area is topographically a flat plain with large rivers. The climate in OKI Regency is tropical, with an average annual rainfall of more than 2500 mm. There are two seasons in this area, namely the rainy and dry seasons. The area of most of the OKI Regency is flat, and the rainfall is high during the rainy season, making part of the OKI Regency dominated by wetlands during the rainy season. For regional planning for welfare and environmental conservation to run in harmony, valid data on wetlands throughout the OKI Regency are needed. The wetland data needs to be used as a reference in determining land use to meet the principles of sustainability. At the beginning of the launch of the Sentinel-1A satellite, Abdikan, et al. (2016) investigated the use of Sentinel-1A data for land cover mapping in urban areas. They found that a dual polarimetric Sentinel-1A can be analyzed rapidly and effectively to produce accurate land cover maps in the long observation period to analyse land cover changes. The fusion method of the SAR Sentinel-1A data and the Landsat-8 OLI optical data was developed to improve land cover classification (Nuthammachot & Stratoulias, 2019). This study found that combining SAR image data and optical images can significantly improve land cover interpretation and classification accuracy. Shareef et al. (2020) also developed a method of combining Sentinel-1A SAR data and Sentinel-2B optical data to produce land cover maps. The best accuracy is obtained by using the SVM algorithm for Sentinel-2B multispectral data, while for Sentinel-1A-VV data, the best accuracy is obtained by applying the Random Forest (RF) algorithm. Ngo et al. (2020) used Sentinel-1A multi-temporal data to map the land cover in the Mekong Delta area, dominated by land with high humidity. Combining the analysis results with field data during the rainy and dry seasons increases the accuracy rate to 94.81% and the Kappa coefficient 0.92.

Sentinel-1A data to identify changes in wetland areas was carried out by Muro et al. (2016). Research has found that Sentinel-1 can detect changes in wetlands due to changes in water surface dynamics, either naturally due to rainfall or agricultural activities. Muro et al. (2016) also recommend using Sentinel-1 imagery to monitor wetland change automatically. SAR Sentinel-1 images are also used to detect and monitor water bodies in time series. This study recommends using Sentinel-1 data, especially in tropical areas where cloud cover varies significantly in the rainy season. Kaplan & Avdan further investigated Sentinel-1 data use, combined with Landsat-8 data and UAV data to monitor wetland dynamically every month (Kaplan and Avdan, 2018). In Sentinel-1 data, VH polarization shows better results than VV polarization. Because wetlands also have vegetation, it is necessary to conduct field observations to sharpen the analysis results. Sentinel-1A data for wetland mapping, after comparing the analysis results with the results from TerraSAR-X / TanDEM-X. Sentinel-1A is broad in scope, and it is possible to extract information on partially or wholly wet meadows using the Shannon Entropy method.

Rapinel et al. (2019) developed an alternative method of wetland mapping based on free remote sensing data. The data used are Sentinel-1, Sentinel-2 image data, validated MODIS data with LIDAR data. This study achieved an accuracy rate of 94% using the random forest (RF) classification. Mahdianpari et al. (2019) achieved an increase in the resolution of the SAR Sentinel-1 and optical Sentinel-2 image analysis on the Google Earth Engine Cloud Computing Platform. The study found that the Sentinel-2 optical composite classification accuracy based on multi-year summer data was more accurate than the Sentinel-1 SAR composite. Combining the two analysis products (SAR and optical) results in a more detailed wetland classification

1.2 Objectives

This article aims to explore the capability of Synthetic Aperture Radar (SAR) Sentinel-1A satellite data to identify wetland areas with various land covers to provide a medium scale wetland map quickly. Wetland data produced is expected to be a valid reference in determining appropriate land use so that it meets the principles of sustainability.

2. METHODS

2.1 Study Area

The site is located at 2.30° S and 104.20° E (Figure 1) with two main Peat Hydrology Unit (PHU), namely, PHU of Sungai Sugihan - Sungai Lumpur and PHU of Sungai Saleh - Sungai Sugihan (source: Ministerial Decree of Environment and Forestry No. SK.129/MENLHK/SETJEN/PKL.0/2/2017). The dominant land uses are oil palm and acacia (Table 1) in OKI Regency, South Sumatra Province. The administrative area of OKI Regency is 17,058.32 km^2 and belongs to the tropical rainforest climate zone. Annual air temperature in OKI Regency ranges between 25 and 32°C, with an average air temperature of 28 °C. In this area, the peak dry season occurs in October, and the peak of the rainy season occurs in February–March.

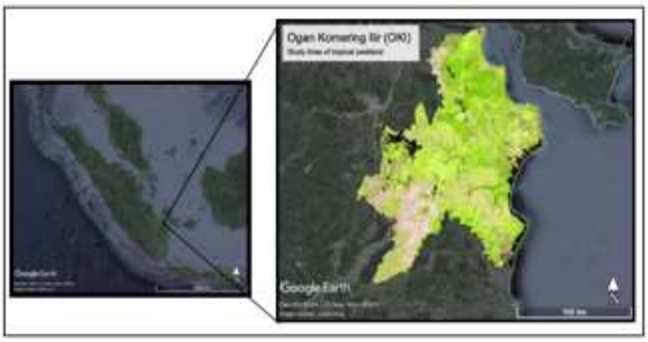

Figure 1. Study site (Google Maps, 2020)

2.2 SAR Sentinel Data

This study used four SAR Sentinel-1A Level 1 data with Ground Range Detected (GRD) level (Table 2). This GRD type SAR data has been processed with multi-look and projected onto WGS 84 coordinates.

Table 1. Parameters Weight based on Environmental Factors Assumptions

Code	Location	Latitude (DD)	Longitude (DD)	Land Used Types
PYB1	Penyabungan	105.43	-3.02	Acacia
PYB2	Penyabungan	105.37	-3.05	Acacia
PYB3	Penyabungan	105.32	-3.03	Acacia
PYB4	Penyabungan	105.39	-3.10	Acacia
KYG1	Kayu Agung	104.86	-3.41	Oil Palm with Shrubs
KYG2	Kayu Agung	104.86	-3.44	Oil Palm with Shrubs
KYG3	Kayu Agung	104.92	-3.46	Oil Palm with Shrubs
KYG4	Kayu Agung	104.95	-3.50	Oil Palm with Shrubs
KYG5	Kayu Agung	104.97	-3.56	Oil Palm with Shrubs

Figure 2 displays composite imagery with the RGB composition of VV polarization, VH polarization, and the difference of backscattering value between VV and VH polarization, respectively. Data specifications used can be seen in Table 2.

Table 2. Specification of SAR Sentinel-1A

Specification	Sentinel-1A
Acquisition time	March 30, 2015 October 2, 2016 March 31, 2017 June 11, 2017 September 3, 2017 December 8, 2017 May 1, 2018
Orbit	*Descending*
Image Mode	IW
Frequency	C-band (5.4 GHz)
Polarization	VV-VH
Product	Level 1 GRD
Spatial Resolution	30 m

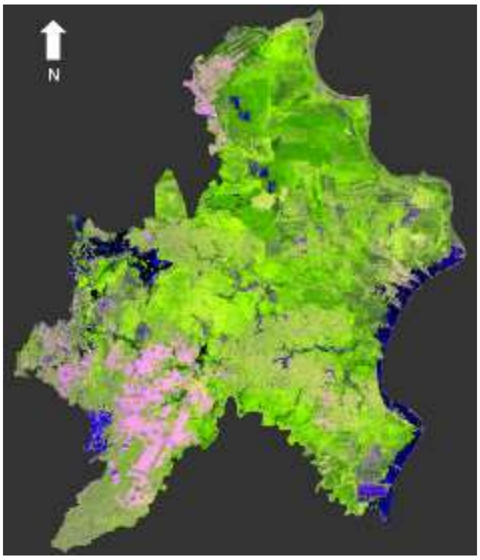

Figure 2. RGB Combination (VV, VH, VV/VH) with an acquisition time of 1 May 2018

2.3 Data Analysis

In this study, the Sentinel-A1 data was processed using the Sentinel Application Platform (SNAP) software (Version 7.0). SNAP is an open-source software developed by ESA to help both users and researchers process Sentinel data. Before the data analysis process, the Sentinel-1A data were filtered using a 7 x 7 Lee Refined Filter, 3 x 3 multi-looking, and corrected using Terrain Correction. Furthermore, the Digital Number (DN) value of each sentinel image pixel is converted into a normalized backscattering coefficient value, as in the equation below:

$$\delta = 10 * \log10(DN2) \quad (1)$$

Where: δ is the normalized value of the backscattering coefficient. The process was carried out using the S1TBX Sentinel 1 toolbox developed by European Space Agency (ESA).

Since all the circumstances such as soil properties, surface roughness, surface features, and radar properties remain constant in each sampling of each field, the model of surface soil moisture and properties of dielectric constants assume that those models are the function of the surface backscatter in both vertical (δVV) and horizontal (δVH) polarization and the local incident angle (θ) (Rao, et al., 2013; Huang, et al., 2019). Additionally, to consider the effect of soil conditions and vegetation cover, we calculate a polarization ratio (δVH/δVV). The backscattering profiles of VV (δVV) polarization and VH polarization (δVH) were then analyzed for all data. The ratio between δVV and δVH (δVV/δVH) values and textures of δVV and δVH was analyzed to identify peatland distribution in OKI Regency.

Identification of peatland is determined on an experimental analysis of soil moisture profile, dielectric constants, and backscattering coefficient values in Siak Regency, Riau Province (Marpaung, et al., 2018), and OKI Regency (Marpaung, et al., 2019; 2020; Sepanie, et al., 2019). We also accessed soil moisture maps from the SEPAL (System for earth observation, data access, processing and analysis for land monitoring, https://sepal.io) platform to monitor soil moisture patterns throughout 2015-2017. SEPAL is an open-source platform that allows users to query and process satellite data and undertake a range of geospatial analyses tailored for different needs. The soil moisture model is based on a Support-Vector-Regression (SVR) machine learning approach, and its model training was performed based on in-situ data from International Soil Moisture Network (ISMN). Estimation of soil moisture has been widely detected using radar imagery. Moreover, a strong correlation was found between groundwater level and the backscatter profile (Jaenicke, et al., 2011). For all these studies, increases in groundwater level (i.e., increase in soil moisture) were positively correlated with an increase in backscatter.

3. RESULT AND DISCUSSION

3.1 Profile of Soil Moisture

Wetland soil moisture profiles must be analyzed because the wetland is recognized by a change in soil moisture or groundwater level. In an undisturbed forest, soil moisture and groundwater levels have a low value during the dry season and have a high value during the rainy season (Marpaung, et al., 2020). The complexity of surface water dynamics in wetland affects the accuracies of maps produced with Sentinel-1, both for temporarily flooded and permanently flooded wetlands. Among these, high-vegetated wetlands subject to permanent or temporary flooding cause considerable confusion in the classifications. The combined use of Sentinel-1 and surface soil moisture profile helps address the complexity in wetland characteristics and obtains better accuracies. This condition can be pictured in Figure 3. It shows that soil moisture profile was relatively high during the wet season in March 2015 and March 2017 compared to October 2016. During a peak dry season in 2016, Penyabungan, located in northern OKI with dominantly covered acacia plantation (Table 1), experienced a decrease in soil moisture. This condition also occurred in an oil palm plantation in southern OKI. Both areas also experienced an increase in soil moisture during a peak wet season in 2015 and 2017.

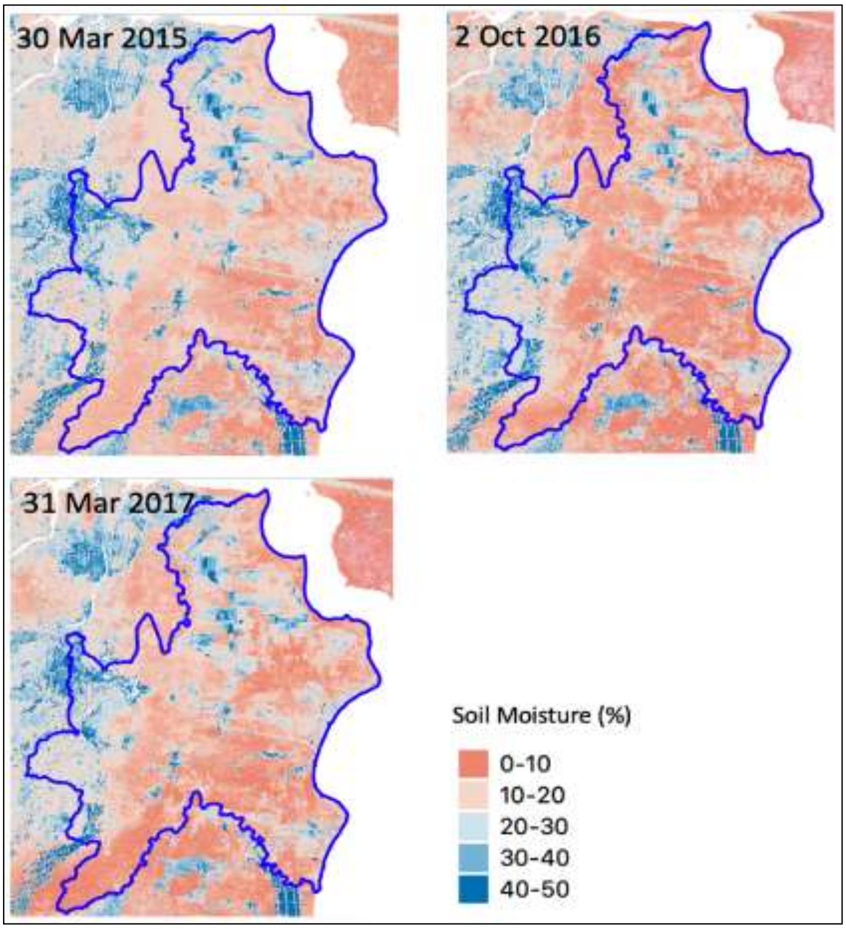

Figure 3. Soil moisture profile in OKI Regency from 2015 to 2017 derived from SEPAL

3.2 Profile of Backscattering SAR Sentinel

Figure 4 shows the backscattering value of VV and VH polarisation for one year from June 6, 2017, to May 1, 2018. The pattern shows VV and VH backscattering profiles at ten observation sites in 2 PHU in OKI Regency, South Sumatra Province. In Penyabungan PHU, the profile of δVH and δVV relatively have relatively similar patterns (Figure 4a and 4b). The profiles decreased in September 2017 then increased in December 2017 and May 2018. Variations in the δVH and δVV values are relatively low with δVH values ranging between -15.3 dB and -12.9 dB, while δVV values are between -10.6 dB and -7.9 dB. The profile of δVH and δVV values in Kayu Agung PHU is almost the same as the δVH and δVV value patterns in Penyabungan PHU (Figure 4c and 4d). However, δVH in the KYG4 has a different pattern. The value of δVH decreased until December 2017 and then increased until May 2018.

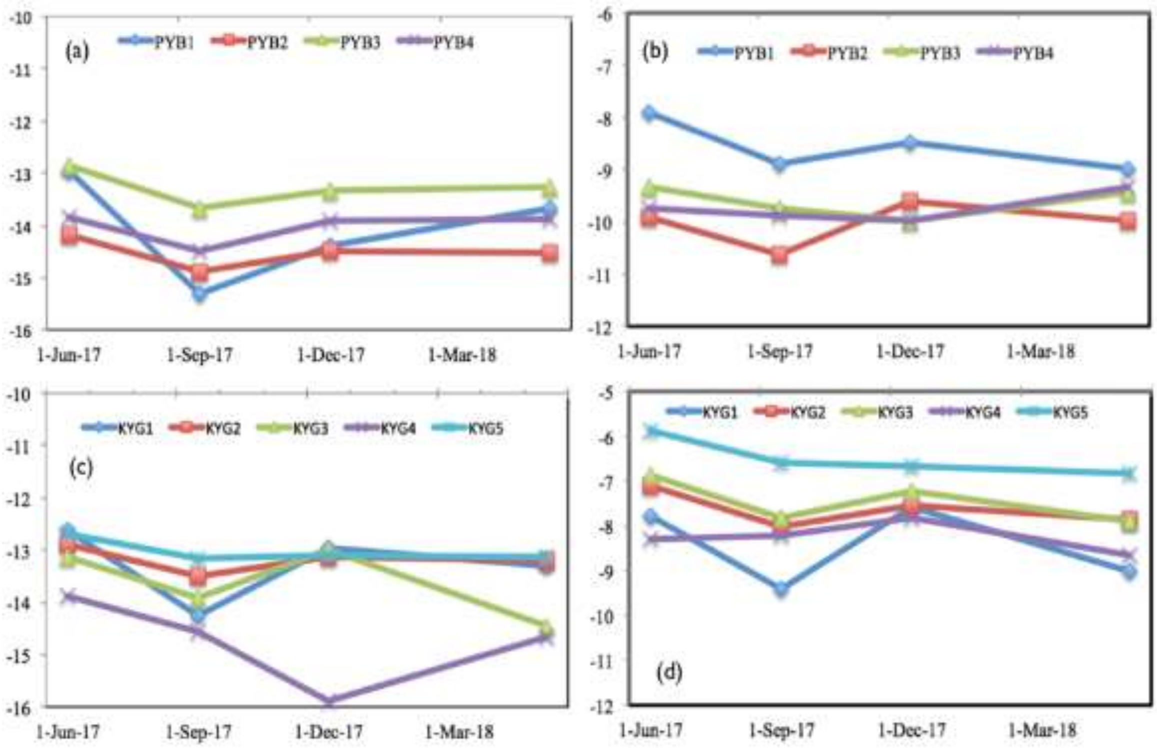

Figure 4. Backscattering profile of VH (left) and VV (right) polarisation at acacia plantation (a, b) and oil palm plantation (c, d)

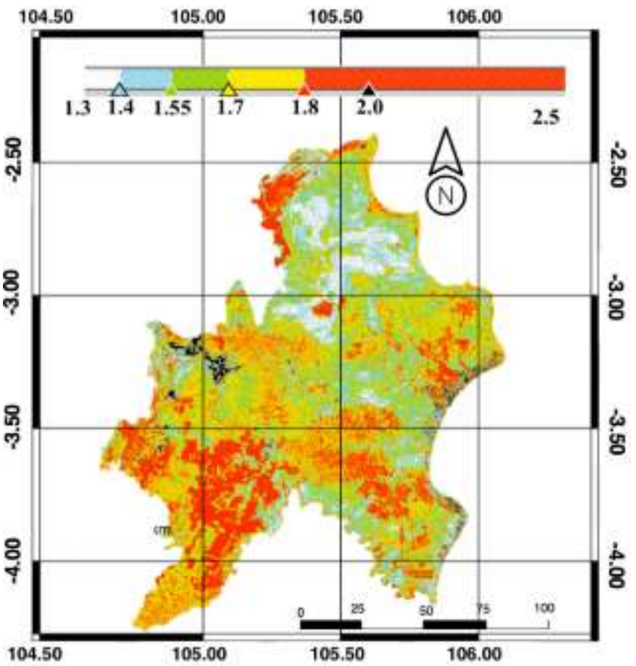

Figure 5. The ratio of VH-VV polarisation in OKI Regency with the acquisition time of 1 May 2018

The ratio of VH-VV backscattering (δVH/δVV) has a high ratio in the southern OKI Regency (Figure 5). The area is mostly a residential and hilly area with a ratio of > 2 (Figure 2). The low δVH/δVV ratio (1.5) is dominantly located in the northern OKI regency and is mostly covered by acacia plantations. Overall, the ratio is relatively the same yearly, with a small variation value (Figure 4).

Based on the analysis, the homogeneity of the VV-backscattering in the study area ranges between 0.75 and 2.0. A low homogeneity occurs in water bodies, with the homogeneity ranging between 0.4 and 0.8.

3.3 Identification of Wetlands

In this study, the information of soil moisture profile with high variation over one year in OKI regency was used to identify wetland initially (Marpaung and Hirano, 2014) Then, the VH-VV ratio's characteristics and the homogeneity were set to identify wetlands in OKI Regency, South Sumatra Province. It shows that the wetland in the OKI regency has a low homogeneity value. The ratio of VH-VV in the wetland covered by acacia and oil palm plantations ranges between 1.3 and 1.6. The ratio ranges between 0.6 and 2.00 in land use of the dense forest. These patterns were classified as a single variable, and Figure 6 shows the estimated wetland distribution. These estimations align with the PHU maps with OKI Regency and ground check in the field. Nevertheless, it is not valid for the cover of dense forest land. This condition is caused by the height and density of trees in the forest.

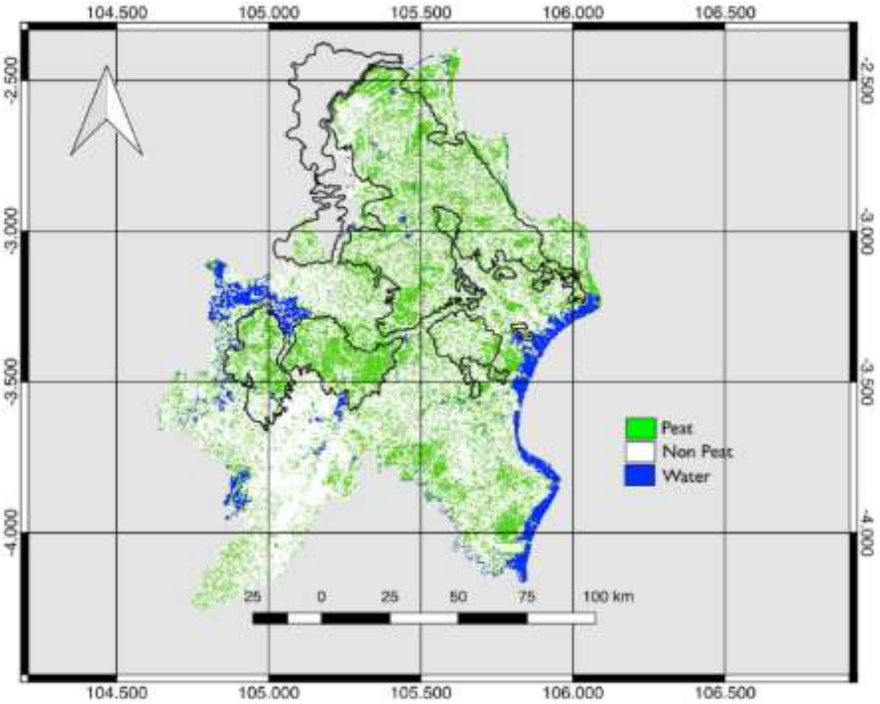

Figure 6. Wetland Delineation in OKI Regency

Identification wetland using Sentinel-1 analysis was observed for each land-use type in the study area. Visual interpretation of the wetland map showed the confusion between upland forest (dominantly as non-peat area) and high-vegetated wetlands. Besides the confusion, visual interpretation of the mode frequency map pointed out the inconsistency for classifying high-vegetated areas either as upland or wetland when using Sentinel-1. This output indicates that C-band operating in VV/VH mode has a low capacity to capture backscattering differences between upland forests and high-vegetated wetlands, such as peat swamp forests. These high-vegetated wetlands in an area cause a disturbance for general wetland delineation when using Sentinel-1. This finding is in line with a high confusion between swamp forests (Mahdianpari, et al., 2018). The assumption of Sentinel-1 being incapable of delineating high-vegetated wetland is underlined by the validation of VH polarization (Figure 4).

Moreover, the frequency map (Figure 5, with low homogeneity) revealed better robustness for high-vegetated areas. This proves again that high-vegetated wetlands contributed largely to confusion using Sentinel-1 classification. The classification of the ratio of dual-polarization (VH and VV) shows the good capabilities of Sentinel-1 for general wetland delineation, provided that only shrubby – sparse oil palm areas. However, this finding is contradicted to a time series data for classifications in herbaceous wetlands with relatively poor accuracies (Mleczko and Mroz, 2018). They obtained better accuracy using dual- and quad-polarimetric X-band radar in herbaceous wetlands because this short wavelength was better at observing double-bounce scattering from grasses and reeds. The accuracy of wetland mapping with Sentinel-1 time series data varies per characterization level. It is found that Sentinel-1 is suitable for the accurate classification of wetland vegetation types. For general wetland delineation and classifying surface water dynamics, inaccuracies are observed mainly for high-vegetated areas. Better accuracies are obtained when characterizing areas with only herbaceous- or shrubby vegetated wetlands.

4. CONCLUSION

This article explored the capability of Synthetic Aperture Radar (SAR) Sentinel-1A satellite data to identify wetland areas with various land covers to provide a medium scale wetland map quickly. Wetland data produced is expected to be a valid reference in determining appropriate land use to meet the principles of sustainability. Using the ratio of backscattering profiles VV (δVV) polarization and VH polarization (δVH) for data sentinel-1 from 2015 to 2018, it is found that the low δVH/δVV ratio (ranges between 1.3 and 1.6) is located in the northern OKI regency and is mostly covered by acacia plantations. The comparison of the wetland delineation with the validation data (ground check data) showed a good fit, so was the comparison with the PHU map. Overall, the δVH/δVV ratio is relatively the same yearly, with a small variation value. Based on the analysis, the homogeneity of the VV-backscattering in the study area ranged between 0.75

and 2.0. A low homogeneity occurs in water bodies, with the homogeneity ranging between 0.4 and 0.8. This study found the capability of Sentinel-1 for the accurate classification of wetland vegetation types, especially herbaceous or shrubby vegetated wetlands, but not for high-vegetated wetlands. The results of this study are expected to be used as a reference in determining land use to meet sustainability principles, where programs for welfare and environmental conservation run in harmony.

ACKNOWLEDGEMENT

The authors would like to thank the School of Environmental Science, University of Indonesia and the Regional Resource Development Technology Center, National Research and Innovation Agency (BRIN) for their support of this research.

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