

ABSTRAK

Banjir merupakan bencana alam dengan frekuensi tertinggi di Indonesia yang menuntut ketersediaan informasi spasial secara cepat dan akurat. Kabupaten Bantul, Daerah Istimewa Yogyakarta, merupakan wilayah rentan banjir periodik akibat topografi dataran rendah di sepanjang Sungai Opak dan Sungai Progo. Pemetaan genangan menggunakan citra optik terkendala tutupan awan yang selalu menyertai kejadian banjir, sementara metode deteksi berbasis citra SAR dengan ambang batas global mengabaikan variasi spasial dan temporal *backscatter* akibat perbedaan tutupan lahan dan perubahan musim. Pelatihan model deep learning untuk segmentasi banjir juga terkendala ketersediaan data label yang sulit diperoleh melalui survei lapangan.

Penelitian ini mengembangkan metode *Seasonal Adaptive HSBA Pseudo-Labeling* yang mengintegrasikan penyesuaian parameter ambang batas berdasarkan tiga fase musim hujan ke dalam kerangka *Hierarchical Split-Based Approach* untuk menghasilkan label klasifikasi banjir tiga kelas secara otomatis, yaitu *Non-Flood*, *Open Water Flood*, dan *Flooded Vegetation* dari citra Sentinel-1 SAR. *Pseudo-label* tersebut digunakan untuk melatih model U-Net dengan masukan lima kanal mencakup *backscatter* VV, VH, selisih temporal kedua polarisasi, dan *confidence score*. Data pelatihan mencakup 37 kejadian banjir periode 2019–2024 dan data pengujian mencakup 11 kejadian periode 2025–2026 yang terpisah secara temporal. Pelatihan menggunakan fungsi *Loss* gabungan *Focal Loss* dan *Weighted Dice Loss* dengan skema *5-Fold Cross Validation*, serta inferensi dengan *Test-Time Augmentation* empat rotasi.

Hasil evaluasi pada data pengujian temporal independen menunjukkan *Overall Accuracy* 98,84%, *mean IoU* 74,68%, dan *mean F1-Score* 83,99%. Kinerja *Open Water Flood* (*IoU* 72,31%) konsisten lebih tinggi dibanding *Flooded Vegetation* (*IoU* 52,91%), dan model tidak menghasilkan kesalahan klasifikasi silang antar kedua kelas banjir. Sistem berhasil memetakan total genangan 12.001,49 ha terdiri dari 5.738,05 ha *Open Water Flood* dan 6.263,44 ha *Flooded Vegetation*. Penelitian ini berkontribusi berupa pendekatan *pseudo-labeling* adaptif berbasis musiman untuk klasifikasi banjir multi-kelas tanpa anotasi manual pada citra SAR di wilayah tropis.

Kata Kunci: klasifikasi banjir, Sentinel-1 SAR, U-Net, *pseudo-labeling*, HSBA

ABSTRACT

Flooding is the most frequent natural disaster in Indonesia, demanding rapid and accurate spatial information. Bantul Regency, Special Region of Yogyakarta, is an area prone to periodic flooding due to its low-lying topography along the Opak and Progo rivers. Flood mapping using optical imagery is hindered by persistent cloud cover during flood events, while SAR-based detection methods relying on global thresholds disregard spatial and temporal backscatter variations caused by differences in land cover and seasonal changes. Training deep learning models for flood segmentation is further constrained by the scarcity of labeled data that is difficult to obtain through field surveys.

This study develops a Seasonal Adaptive HSBA Pseudo-Labeling method that integrates threshold parameter adjustments across three wet-season phases into the Hierarchical Split-Based Approach framework to automatically generate three-class flood classification labels — Non-Flood, Open Water Flood, and Flooded Vegetation — from Sentinel-1 SAR imagery. The generated pseudo-labels are used to train a U-Net model with five input channels comprising VV and VH backscatter, temporal difference of both polarizations, and a confidence score. Training data encompass 37 flood events from 2019–2024 and testing data cover 11 temporally independent events from 2025–2026. The model is trained using a combined Focal Loss and Weighted Dice Loss function with 5-Fold Cross Validation, and inference is performed with four-rotation Test-Time Augmentation.

Evaluation on temporally independent testing data yields a mean Overall Accuracy of 98.84%, mean IoU of 74.68%, and mean F1-Score of 83.99%. Open Water Flood classification (IoU 72.31%) consistently outperforms Flooded Vegetation (IoU 52.91%), and the model produces no cross-classification errors between the two flood classes. The system successfully maps a total inundation area of 12,001.49 ha consisting of 5,738.05 ha of Open Water Flood and 6,263.44 ha of Flooded Vegetation. This study contributes a season-adaptive pseudo-labeling approach for multi-class flood classification without manual annotation on SAR imagery in tropical regions.

Keywords: *flood classification, Sentinel-1 SAR, U-Net, pseudo-labeling, HSBA*