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Mapping Vegetation Condition Before and After the 2025 Flood Using Sentinel-2-Based NDVI in Pidie Jaya Regency

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Abstract

The major flood that affected Pidie Jaya Regency in November 2025 caused substantial changes in land-surface conditions, including vegetation and agricultural areas. However, spatial information on vegetation conditions before and after the flood remains limited. This study aimed to assess spatial patterns of vegetation conditions before and after the 2025 flood in Pidie Jaya Regency, Aceh Province, using the Normalized Difference Vegetation Index (NDVI) derived from Sentinel-2 imagery. Sentinel-2 Surface Reflectance (Level-2A) imagery was processed using the Google Earth Engine (GEE) platform. Imagery acquired during 1 October–25 November 2025 was used to represent pre-flood conditions, while imagery acquired during 26 November–15 December 2025 was used to represent post-flood conditions. Images from each period were composited using the median value, and NDVI was calculated from the Red (Band 4) and Near-Infrared (NIR; Band 8) bands. The results revealed heterogeneous spatial patterns of NDVI response. The Southern area of Meureudu, Meurah Dua, and Ulim Districts showed apparent shifts from areas with relatively high pre-flood NDVI values (0.6–1.0) toward lower NDVI classes (0.2–0.5) after the flood. This pattern is consistent with vegetation disturbance and changes in land-surface conditions associated with flooding. In contrast, several northern lowland areas exhibited an increase in NDVI from approximately 0.0–0.2 to 0.3–0.5. This increase does not necessarily indicate vegetation recovery but may be associated with changes in surface conditions, moisture, and the deposition and subsequent drying of flood sediments.

Keywords: *pidie jaya flood, vegetation condition, sentinel-2 ndvi, pre- and post-flood assessments*

Abstrak

Banjir besar yang melanda Kabupaten Pidie Jaya pada November 2025 menyebabkan perubahan kondisi permukaan lahan, termasuk pada kawasan vegetasi dan pertanian. Namun, informasi spasial mengenai perubahan kondisi vegetasi sebelum dan sesudah kejadian banjir masih terbatas. Penelitian ini bertujuan untuk menganalisis pola perubahan kondisi vegetasi sebelum dan sesudah banjir tahun 2025 di Kabupaten Pidie Jaya, Provinsi Aceh, menggunakan *Normalized Difference Vegetation Index* (NDVI) berbasis citra Sentinel-2. Data yang digunakan berupa citra Sentinel-2 *Surface Reflectance* (Level-2A) yang diolah melalui platform *Google Earth Engine* (GEE). Citra pada periode 1 Oktober–25 November 2025 digunakan untuk merepresentasikan kondisi prabanjir, sedangkan citra pada periode 26 November–15 Desember 2025 digunakan untuk merepresentasikan kondisi pascabanjir. Citra pada masing-masing periode dikomposit menggunakan nilai median, kemudian NDVI dihitung menggunakan kanal Red (Band 4) dan *Near-Infrared* (NIR; Band 8). Hasil menunjukkan adanya pola respons NDVI yang heterogen. Wilayah Selatan Kecamatan Meureudu, Meurah Dua, dan Ulim menunjukkan perubahan visual dari area dengan NDVI relatif tinggi (0,6–1,0) sebelum banjir menjadi kelas NDVI yang lebih rendah (0,2–0,5) setelah banjir. Pola tersebut konsisten dengan gangguan vegetasi dan perubahan kondisi permukaan yang berkaitan dengan genangan serta sedimentasi lumpur. Sebaliknya, beberapa wilayah dataran rendah bagian utara menunjukkan peningkatan NDVI dari sekitar 0,0–0,2 menjadi 0,3–0,5. Peningkatan tersebut tidak serta-merta menunjukkan pemulihan vegetasi, tetapi dapat berkaitan dengan perubahan kondisi permukaan, kelembapan, serta pengendapan dan pengeringan lumpur pascabanjir.

Kata Kunci: *banjir pidie jaya, kondisi vegetasi, ndvi sentinel-2, analisis prabanjir dan pascabanjir*

1. Introduction

The Great Sumatra Flood that occurred on 26 November 2025 and affected large parts of Sumatra, including Aceh, North Sumatra, and West Sumatra Provinces, was one of the most significant hydrometeorological disasters in the past decade [1]. Pidie Jaya Regency was one of the areas in Aceh that experienced significant impacts from the event, leading to the declaration of an emergency response status [2]. Geographically, Pidie Jaya Regency is located on the northern coast of Aceh Province and directly faces the Malacca Strait, with characteristics that make the region vulnerable to hydrometeorological disasters [3]. This vulnerability is further influenced by the Krueng Meureudu Watershed, which extends from mountainous areas in the south to lowland areas in the north , causing runoff from the upstream region to rapidly concentrate toward downstream areas during extreme rainfall events [4]. During the flood event, Meureudu District, Pidie Jaya Regency, recorded rainfall of 376.6 mm during 25–26 November 2025 from Tropical Cyclone Senyar [5], which was high rainfall amounts recorded in Aceh during the period. The extreme rainfall increased water input into the Krueng Meureudu Watershed and contributed to increased river discharge, resulting in river overflow and flooding in downstream areas. In addition to extreme rainfall, the condition of forest cover in the upstream area also warrants attention. Illegal logging activities in the mountainous forest areas of Pidie Jaya Regency had been reported prior to the flood event [4].

Forest degradation and changes in forest cover can reduce infiltration capacity and increase surface runoff, potentially increasing flood vulnerability [6], [7] The combination of these environmental and hydrological characteristics contributed to the substantial impacts of the 2025 flood in Pidie Jaya Regency. The flooding affected productive agricultural areas, particularly rice fields located in lowland areas. Flood flows can transport sediment and deposit muddy materials over agricultural land. These conditions, together with inundation and physical disturbances caused by water flow, can damage crops and alter vegetation conditions in affected areas [8]. Therefore, changes in vegetation density can serve as a spatial indicator for evaluating the extent and magnitude of flood impacts on vegetation conditions.

Conventional field-based assessments of post-disaster vegetation damage have several limitations, including relatively high operational cost. Remote sensing technology provides an efficient alternative for spatially assessing disaster impacts over large areas [9]. Sentinel-2 imagery offers relatively high spatial and temporal resolutions, making it suitable for monitoring changes in vegetation conditions before and after flood events. By integrating Sentinel-2 imagery with the Normalized Difference Vegetation Index (NDVI), changes in vegetation condition and relative vegetation density can be quantitatively identified and spatially mapped [10].

Previous studies have examined various aspects of flood hazards in Pidie Jaya Regency; however, most have focused on mitigation and flood hazard zoning [11], [12], [13]. Meanwhile, studies examining changes in vegetation conditions before and after the 2025 flood event in Pidie Jaya Regency remain limited. Therefore, spatial analysis of vegetation changes is needed to provide an overview of vegetation responses to the flood event. Based on these considerations, this study aims to analyse changes in vegetation conditions before and after the 2025 flood in Pidie Jaya Regency using Sentinel-2 imagery and the Normalized Difference Vegetation Index (NDVI). The analysis focuses on comparing NDVI values and their spatial distributions before and after the flood event to identify changes in vegetation conditions within the affected areas. The results are expected to provide a spatial overview of vegetation changes as an indicator of flood impacts and serve as preliminary information to support post-disaster assessment and recovery.

2. Material and Methods

This study was conducted in Pidie Jaya Regency, Aceh Province, Indonesia, geographically located between 96°8′0″–96°16′0″ E and 4°56′25″–5°14′51″ N. The primary dataset consisted of Sentinel-2 Surface Reflectance (Level-2A) imagery obtained through the Google Earth Engine (GEE) platform. Sentinel-2 imagery was analyzed using two temporal periods representing pre- and post-flood conditions. The pre-flood period covered 1 October–25 November 2025, while the post-flood period covered 26 November–15 December 2025. The workflow of this study was displayed on Figure 1.

Sentinel-2 imagery within each period was processed using cloud and cloud-shadow masking to minimize atmospheric and cloud-related effects. The available scenes within each temporal period were then aggregated using the median reducer to generate representative composite images for the pre-flood and post-flood conditions. Thus, the analysis was based on two temporal median composites representing vegetation conditions before and after the flood event.

The Normalized Difference Vegetation Index (NDVI) was calculated separately for the pre-flood and post-flood composites using the Near-Infrared (NIR; Band 8) and Red (Band 4) spectral bands according to following Equation [14]:

$$\mathrm{NDVI} = \frac{\mathrm{Band\ 8} - \mathrm{Band\ 4}}{\mathrm{Band\ 8} + \mathrm{Band\ 4}}$$

The resulting NDVI values theoretically ranged from −1 to +1 and were categorized into four vegetation-density classes: concern non-vegetation (−1), low density (0.1–0.3), moderate density (0.3–0.5), and high density (>0.5) [15]. The same classification criteria were applied to both temporal composites to facilitate consistent visual interpretation of vegetation conditions before and after the flood event.

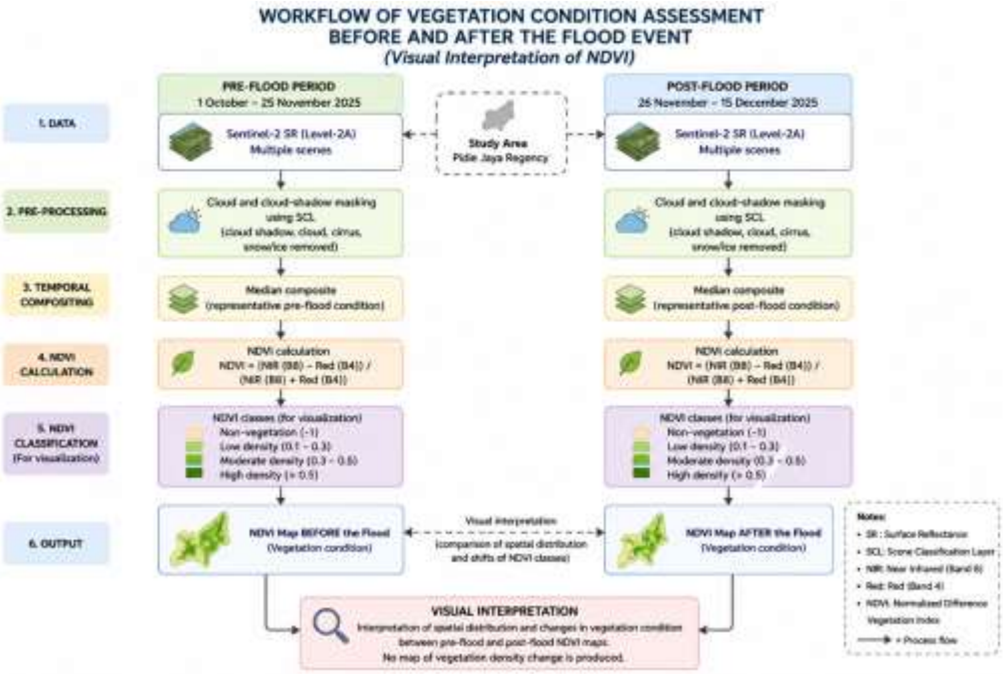

Figure 1. Workflow of Sentinel-2-based NDVI processing and visual interpretation of vegetation conditions before and after the 2025 flood in Pidie Jaya Regency

Changes in vegetation conditions were assessed by comparing the spatial distribution and shifts of NDVI density classes between the pre-flood and post-flood composites. The comparison was conducted through spatial interpretation of the NDVI maps to identify areas showing changes in vegetation density following the flood event. The analysis was designed as a pre- and post-flood spatial assessment and was not intended to establish a definitive causal relationship between the flood event and observed vegetation changes. Accordingly, the study presents and compares the pre-flood and post-flood NDVI maps through visual spatial interpretation rather than producing a separate vegetation-change map.

3. Results and Discussion

Based on the applied methodological framework, this study identified spatial patterns of vegetation conditions before and after the November 2025 flood event using Sentinel-2-based NDVI mapping in Pidie Jaya Regency, as illustrated in Figure 2. The map displays variations in spectral NDVI values representing vegetation cover conditions across the study area, categorized into two temporal phases: pre-flood (**Figure 2a**) and post-flood (**Figure 2b**). In general, the post-flood NDVI map shows a widespread spatial shift toward lower vegetation-density classes in several parts of Pidie Jaya Regency. This spatial pattern is interpreted in the context of the November 2025 flood event. This shift in spectral patterns aligns closely with the topographic and physiographic characteristics of the region. In general, the spatial analysis demonstrates a clear contrast in NDVI values across Pidie Jaya Regency, with the mountainous areas in the south showing relatively high NDVI values (0.6–1.0), while the low-lying northern plains were predominantly characterized by lower NDVI values (0.0–0.2). This spatial pattern corresponds to the contrasting physiographic characteristics of the region, from densely vegetated mountainous areas in the south to lowland agricultural and wetland areas in the north.

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Temporal observations reveal complex spectral dynamics driven by the extreme hydrometeorological flood that struck the region. Prior to the disaster (**Figure 2a**), the northern coastal lowlands were dominated by cream to pale blue shades, corresponding to low NDVI values (0.0 to 0.2). These low NDVI values may correspond to areas with limited green vegetation, including wet agricultural surfaces, water bodies, exposed soil, and other non-vegetated surfaces. High surface-water content and limited green vegetation can contribute to low NDVI values in such areas [16][17]. Conversely, the post-disaster imagery (**Figure 2b**) reveals a highly heterogeneous shift in spectral response across the study area. The extreme flood generated high-velocity runoff that mobilized and transported substantial amounts of sediment from the upstream catchment, resulting in extensive mud deposition across downstream areas. In some locations, the deposited mud reportedly reached nearly 2 m in thickness deposition over vegetated surfaces.

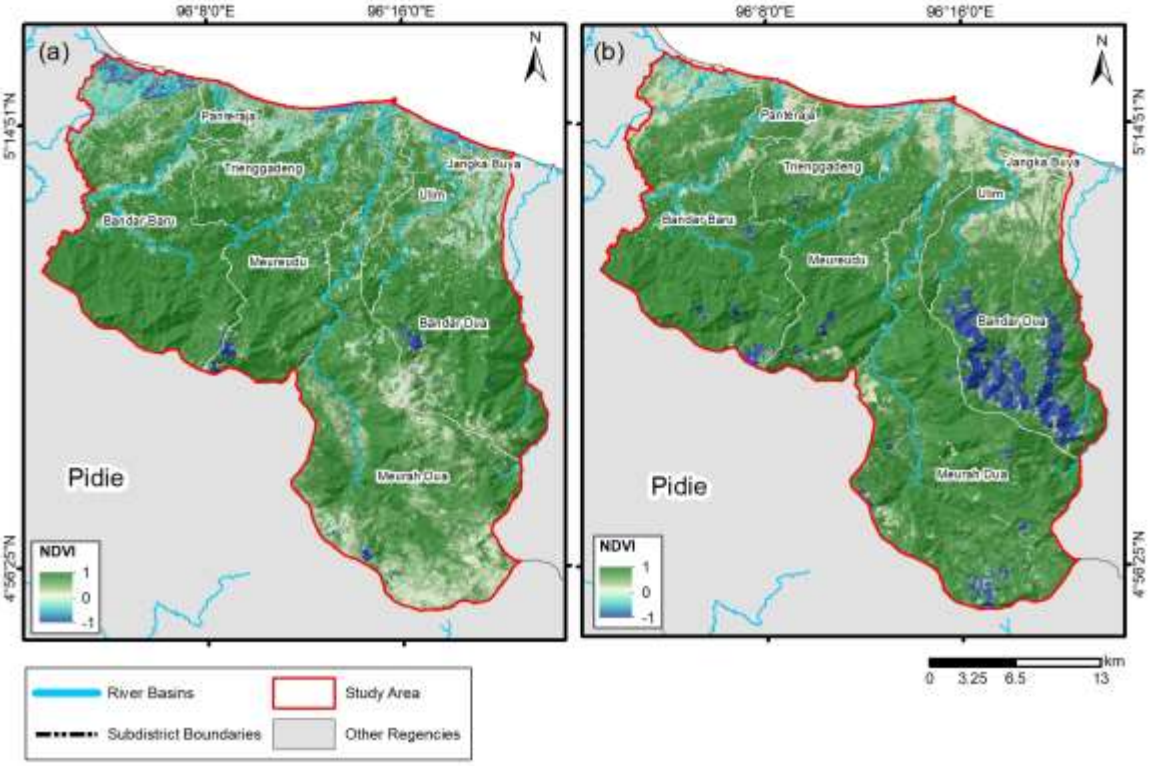

Figure 2. NDVI spatial distribution map of Pidie Jaya Regency (a) pre-flood and (b) post-flood derived from Sentinel-2 imagery.

Based on visual comparison of the two NDVI maps, the most apparent changes in vegetation-density patterns were observed in Southern area of Meureudu, Meurah Dua, and Ulim. In these areas, dense vegetation cover characterized by pre-flood NDVI values of 0.6 to 1.0 (indicated by dark green in **Figure 2a**) suffered a sharp decline, areas that appeared as higher-density vegetation in the pre-flood map were visually observed to correspond to lower-density classes in the post-flood map (0.2 to 0.5, indicated by cream and light green shades in Figure 2b). The observed spatial patterns may be related to physical disturbances associated with flooding, including direct damage to vegetation.

Meanwhile, in the northern coastal areas, a spectral shift occurred from pale blue shades to a brighter appearance. This pattern may indicate changes in surface conditions following flood recession, potentially including the deposition and subsequent drying of fine sediment on previously water-saturated surfaces. The extensive mud deposition is particularly relevant to the interpretation of the post-flood NDVI response in Pidie Jaya. A thick sediment layer can substantially modify the original land-surface characteristics by covering vegetation, agricultural soil, and previously water-saturated surfaces. Consequently, the spectral response recorded by Sentinel-2 after the flood may represent a combination of vegetation condition and the optical properties of the newly deposited sediment. Therefore, an increase in NDVI in some northern lowland areas should not necessarily be interpreted as vegetation recovery, but rather as a possible response to changes in surface composition and moisture conditions following sediment deposition and flood recession.

As the floodwaters receded, the drying mud deposits on the land surface experienced a change in spectral reflectance properties [18]. The spectral response from dry silt deposit (dry silt reflectance) is significantly higher than that of pre-flood wet paddy fields and aquaculture ponds, which can alter the spectral response and result in relatively higher NDVI values compared with the pre-flood condition. This condition highlights a forced surface transformation from productive agricultural and aquaculture land into barren mud deposits (dead silt deposits). The blank or masked areas in **Figure 2b** correspond to pixels excluded during cloud and cloud-shadow masking and therefore were not interpreted as surface conditions. A summary of the spatial analysis regarding changes in vegetation density, sediment spectral effects, and image coverage conditions for each district is presented in **Table 1**.

Table 1. Visual interpretation of vegetation condition before and after the 2025 flood across Pidie Jaya Regency

District	Visual interpretation of NDVI patterns
Bandar Dua	The northern lowlands showed a shift from relatively low NDVI values (0.0–0.2), associated with wet agricultural areas, to relatively higher NDVI values (0.3–0.5) after the flood. This pattern may reflect changes in surface conditions associated with sediment deposition and subsequent drying.
Meureudu, Meurah Dua, and Ulim	The most apparent changes in vegetation-density patterns were observed in these areas, with areas showing relatively high pre-flood NDVI values becoming associated with lower NDVI classes after the flood. The observed pattern may be related to vegetation disturbance, inundation, and extensive mud deposition.
Jangka Buya	Relatively limited spatial changes were observed compared with the other districts, with visible differences mainly occurring around riparian areas and river corridors.
Trienggadeng	Several localized areas showed a shift toward lower NDVI classes, particularly around river channels and residential areas.
Panteraja	Relatively limited changes were observed between the two periods. Areas with low NDVI remained predominantly associated with coastal and water-covered surfaces.
Bandar Baru	No prominent spatial changes in NDVI patterns were visually observed between the pre-flood and post-flood maps.

The contrasting NDVI patterns, characterized by lower values in several central and southern areas and relatively higher values in some northern lowland areas, indicate substantial changes in surface conditions across parts of Pidie Jaya Regency following the flood event. These changes are likely influenced by the combined effects of vegetation disturbance, inundation, sediment deposition, and changes in surface moisture following flood recession. The heterogeneous NDVI response observed across Pidie Jaya indicates that the post-flood spectral signal cannot be interpreted solely as vegetation loss. In areas where vegetation was directly disturbed or covered by floodwater and sediment, lower NDVI values were observed. In contrast, areas that had low pre-flood NDVI due to wet surfaces or limited vegetation could exhibit relatively higher post-flood values following sediment deposition and drying. This finding emphasizes the importance of considering land-surface conditions when interpreting post-flood NDVI imagery

Overall, the results demonstrate that Sentinel-2-based NDVI mapping can provide a useful spatial representation of vegetation conditions before and after a flood event, particularly for rapid visual assessment over a broad area. The resulting spatial information may support preliminary post-flood assessment and help identify areas that warrant further field-based investigation and rehabilitation planning. This study has several limitations. The assessment was based on spatial comparison of Sentinel-2 NDVI composites representing two periods before and after the flood event and was intended primarily for rapid visual assessment. Therefore, the observed NDVI differences should not be interpreted as a definitive measure of flood-induced vegetation loss or as evidence of a direct causal relationship. Further multi-temporal observations and field-based assessments would be useful to distinguish flood-related vegetation disturbance from other factors that may influence NDVI.

4. Conclusion

This study assessed the spatial patterns of vegetation conditions before and after the 2025 flood in Pidie Jaya Regency using Sentinel-2 imagery and the Normalized Difference Vegetation Index (NDVI). The comparison of pre-flood and post-flood NDVI maps revealed distinct spatial variations in vegetation conditions across the regency. Areas in the southern and central parts, particularly Meureudu, Meurah Dua, and Ulim, showed apparent shifts from relatively high pre-flood NDVI values (0.6–1.0) toward lower NDVI classes (0.2–0.5) after the flood. This pattern is consistent with vegetation disturbance and changes in land-surface conditions associated with flooding and extensive sediment deposition.

In contrast, several northern lowland areas showed relatively higher post-flood NDVI values, with values increasing from approximately 0.0–0.2 before the flood to 0.3–0.5 after the event. This increase should not necessarily be interpreted as vegetation recovery. The extensive sediment deposition documented following the flood, including mud deposits reaching nearly 2 m at some locations, together with changes in surface moisture following flood recession, may have altered the spectral response of previously wet or inundated surfaces. These contrasting NDVI responses demonstrate that post-flood vegetation assessment requires consideration of local land-surface conditions, particularly in areas affected by substantial sediment deposition.

Overall, Sentinel-2-based NDVI mapping provided useful spatial information for the rapid visual assessment of vegetation conditions before and after the 2025 flood over a broad area. The resulting maps can serve as preliminary spatial information for identifying areas that warrant further field investigation, agricultural rehabilitation, and post-flood land recovery. However, the observed differences represent spatial patterns between two temporal conditions and should not be interpreted as a definitive quantitative measure or causal attribution of flood-induced vegetation loss. Future studies integrating rainfall and river-discharge data, field validation, and longer-term multi-temporal observations are recommended to further distinguish flood-associated vegetation disturbance from seasonal and other environmental variations.

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