



INTISARI

Longsor merupakan salah satu bencana alam yang sering terjadi di Indonesia, menyebabkan kerusakan infrastruktur dan korban jiwa. Upaya mitigasi dilakukan melalui pendekatan fisik dan non-fisik, di mana metode non-fisik umumnya lebih disukai karena efisien dan mudah diterapkan. Salah satu metode non-fisik yang paling banyak digunakan adalah Sistem Peringatan Dini Longsor (LEWS), baik pada skala lokal maupun regional. Meskipun LEWS skala lokal memberikan informasi secara detail terhadap pemantauan kejadian longsor, namun cakupannya terbatas sehingga tidak sebanding dengan banyaknya kejadian longsor yang terjadi di Indonesia. Oleh karena itu, pengembangan LEWS skala regional menjadi penting. Sebagian besar LEWS skala regional hanya menggunakan parameter hujan saja sebagai faktor pemicu kejadian longsor tanpa memperhitungkan kondisi kejenuhan tanah, dimana hal ini dapat memicu ketidakakuratan dalam prediksi kejadian longsor. Penelitian ini bertujuan untuk meningkatkan akurasi LEWS dengan menambahkan parameter kelembaban tanah dalam analisis prediksi kejadian longsor.

Penelitian dilakukan di Kabupaten Girimulyo, Kulon Progo, D.I. Yogyakarta, dengan fokus pada kejadian longsor tahun 2014–2024. Estimasi nilai kelembaban tanah di lokasi kejadian longsor menggunakan pemodelan berbasis PC-Raster, sedangkan estimasi curah hujan menggunakan interpolasi Inverse Distance Weighting Method (IDW). Kombinasi kedua parameter ini digunakan untuk menentukan ambang batas longsor, yang diklasifikasikan menjadi dua: (1) ambang batas bawah untuk membedakan antara kejadian longsor dan tidak longsor, dan (2) ambang batas atas berdasarkan probabilitas kejadian longsor terlampaui antara (10%–50%) yang memiliki hasil statistik terbaik. Kedua garis ambang batas ini kemudian akan membagi area penelitian menjadi tiga tingkatan berdasarkan pembacaan nilai curah hujan dan kelembaban tanah. Secara paralel, Peta Kerentanan Longsor (LSM) dibuat menggunakan metode Frequency Ratio (FR) dan divalidasi menggunakan perhitungan Area Under Curve (AUC). Integrasi LSM dan ambang batas dilakukan melalui matriks logic-operator untuk menentukan kriteria peringatan dini longsor.

Hasil menunjukkan bahwa model kelembaban tanah memiliki performa baik ($R^2 > 0,80$; RMSE $< 0,15$; NSE = 0,69). Kombinasi curah hujan dan kelembaban tanah menghasilkan nilai AUC yang memuaskan yaitu 0,82. Ambang batas bawah menghasilkan nilai *hit rate* (HR) 1, akurasi 0,29, *false alarm rate* (FAR) 0,74, dan Euclidean distance (Ed) 0,74. Ambang batas atas terbaik berada pada tingkat probabilitas terlampaui 30%, dengan akurasi 82%, HR 0,68, FAR 0,17, dan Ed 0,36. Hubungan antara curah hujan dan kelembaban tanah mengikuti fungsi linear menurun ($y = -mx + c$), menunjukkan bahwa semakin tinggi kelembaban tanah, semakin rendah curah hujan yang dibutuhkan untuk memicu longsor. LSM yang dikembangkan menggunakan metode FR menghasilkan nilai AUC yang cukup baik sebesar 0,702. Integrasi LSM tersebut dengan ambang batas menghasilkan akurasi prediksi longsor yang sangat baik di atas 80%.

Kata kunci : Hujan, Kelembaban Tanah, Ambang Batas, Sistem Peringatan Dini Longsor, Metode Statistik



ABSTRACT

Landslides are among the most devastating natural hazards in Indonesia, frequently resulting in significant damage to infrastructure and loss of life. To mitigate these risks, both structural and non-structural approaches are employed, with the latter often preferred due to lower costs and easier implementation. Among non-structural measures, Landslide Early Warning Systems (LEWS) have gained prominence at both local and regional scales, as they provide timely alerts that enable communities to take preventive actions. While local-scale LEWS offer detailed, real-time monitoring, the widespread nature of landslide events in Indonesia necessitates the development of an effective regional-scale LEWS. Currently, most regional LEWS rely on rainfall thresholds alone, which can lead to inaccuracies if soil conditions are not considered. This study aims to enhance the accuracy of LEWS by incorporating soil moisture data into the threshold-based model.

The study was conducted in Girimulyo District, Kulon Progo, D.I. Yogyakarta, and focused on landslide events that occurred between 2014 and 2024. A soil moisture model was developed using the PC-Raster platform and validated with field data collected from four installed sensors. This model was then used to estimate soil moisture values at landslide locations. Rainfall data at these locations were estimated using Inverse Distance Weighting (IDW) interpolation. The combined rainfall and soil moisture data were used to develop the threshold for landslide initiation. These thresholds were classified into two types: (1) a lower threshold to distinguish landslide events from non-events, and (2) an upper threshold derived from five exceedance probabilities (10%, 20%, 30%, 40%, and 50%), with the optimal threshold selected based on statistical performance. The two threshold lines then divided the area into three levels based on the rainfall and soil moisture value. In parallel, a Landslide Susceptibility Map (LSM) was developed using the Frequency Ratio (FR) method and validated using the Area Under the Curve (AUC). The threshold classification and LSM were then integrated through a matrix of logical operators to assess landslide warning criteria within the LEWS.

The soil moisture modeling produced strong results, with an average R^2 value exceeding 0.80, a root mean square error (RMSE) below 0.15, and a Nash–Sutcliffe efficiency (NSE) coefficient of 0.69. These metrics indicate that the model is reliable for estimating soil moisture values across the study area. The integration of rainfall and modeled soil moisture data also showed a strong correlation with the landslide inventory, achieving an area under the curve (AUC) value of 0.82, which reflects excellent predictive performance. The lower threshold achieved a hit rate (HR) of 1, an accuracy of 0.29, and both a false alarm rate (FAR) and Euclidean distance (Ed) of 0.74. The best-performing upper threshold was at the 30% exceedance probability, with an accuracy of 82%, HR of 0.68, FAR of 0.17, and Ed of 0.36. These proposed thresholds followed the functional relationship $y = -mx + c$, where y is rainfall and x is soil moisture, and the negative slope ($-m$) signifies that as soil moisture increases, the rainfall required to trigger a landslide decreases. The LSM developed using the Frequency Ratio method performed well with an AUC value of 0.702. Integration of the threshold model with the LSM achieved a predictive accuracy above 80%, demonstrating its effectiveness in issuing early warnings and supporting disaster risk reduction efforts in landslide-prone areas.

Keywords: Rainfall, Soil Moisture, Threshold, Landslide Early Warning System, Statistical Metric