https://jurnal.iaii.or.id/index.php/RESTI/article/view/7420

Regional Urban Heat Island Risk Mapping Using PCA and Fuzzy Clustering

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DOI:

https://doi.org/10.29207/resti.v10i5.7420

Keywords:

fuzzy clustering, principal component analysis, remote sensing, spatial risk mapping, urban heat island

Abstract

Urban Heat Island (UHI) effects pose increasing challenges in rapidly urbanizing tropical regions, where land-cover transformation and population concentration intensify spatial thermal risk. This study proposes an integrated Principal Component Analysis-Fuzzy C-Means spatial framework to classify and map regional UHI risk across Sulawesi Island, Indonesia, using multi-source geospatial data. Land surface temperature, vegetation condition, built-up intensity, and population density were harmonized on a 1 km grid for the 2024-2025 period. Dimensionality reduction was performed to extract dominant spatial variance, followed by fuzzy clustering to represent gradual transitions in UHI risk. The results indicate a strong dominance of the first principal component, explaining more than 99.9% of total variance in both years, reflecting a stable integrated urban-environmental gradient. Three UHI risk classes were delineated, representing low-risk cool areas, moderate-risk transitional zones, and high-risk densely built urban regions. Although a two-cluster solution achieved the lowest numerical validity, a three-cluster configuration was adopted to better capture transitional urban conditions relevant to spatial planning. The resulting maps reveal concentrated UHI risk in major urban centers, particularly Makassar and expanding peri-urban corridors. The proposed framework provides a robust, interpretable, and policy-relevant approach for regional-scale UHI risk assessment in data-limited tropical environments.