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Data-driven agroclimatic risk zoning for maize cultivation in Indonesia using long-term daily climate indicators

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Abstract

Annual climate summaries can conceal short-duration hazards relevant to maize planning in Indonesia. This study develops national agroclimatic risk zones using daily data from the National Aeronautics and Space Administration Prediction of Worldwide Energy Resources (NASA POWER) project for 2001–2025. The retained 310,454 daily records represent one grid cell per province and yield 850 province-year observations. Fourteen climate indicators were standardized, and principal component analysis (PCA) retained four components explaining 85.58% of the variance. K-Means++ solutions with two to eight clusters were evaluated. The highest silhouette score favoured three clusters, the lowest Davies-Bouldin index (DBI) favoured eight, and the highest Calinski-Harabasz index (CHI) favoured two. Four clusters were retained as an explicit climate-only interpretive choice balancing internal validity, stability, parsimony, and distinct climate profiles, rather than as a unique statistical optimum. These clusters correspond to three risk levels: Cluster 1, low; Clusters 2 and 3, moderate; and Cluster 4, high. The high-risk class represents the seasonally dry, heat-exposed corridor

encompassing Jawa Timur, Bali, and Nusa Tenggara. Maize productivity data from Statistics Indonesia (Badan Pusat Statistik, BPS) for 2020–2024 provided 164 observations from 33 provinces. Province-clustered inference accounted for repeated annual observations. Neither the six-indicator model ($F(6, 32) = 2.284$, $p = 0.060118$) nor the cluster-membership model ($F(3, 32) = 2.448$, $p = 0.081657$) reached statistical significance at the 5% level; their descriptive R^2 values were 0.126 and 0.091, respectively. Province-clustered bivariate tests with Holm–Bonferroni adjustment identified a statistically significant association only for heat stress days (raw $p = 0.006598$; adjusted $p = 0.039589$). This exploratory association was not supported by the multivariable model. Non-significance does not establish the absence of an association. The zones describe climatic exposure rather than validated differences in realized maize yield.

Keywords

Agroclimatic risk zoning, Maize suitability, NASA POWER, Principal component analysis, K-Means++ clustering, Indonesia.