Comprehensive Analysis of S-wave Intensity Prediction in New Zealand Earthquakes: A Multilevel Modeling Approach

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Earthquake early warning systems (EEWS) are crucial in seismically active regions like New Zealand. Various methodologies are used in EEWS to generate warnings, with estimating earthquake intensity being particularly important as it is directly related to ground shaking and damage probability. Earthquakes produce two wave types: Primary (P) and secondary (S). P-waves travel faster but are less destructive than S-waves. Therefore, most EEWS detect P-waves, estimate the intensity of the following S-waves, and issue a warning within those precious few seconds. This study aims to identify the best factors for S-wave intensity estimation, explore the impact of parameters (P-wave, station characteristics, earthquake-id, year-index), and develop a nationwide S-Wave intensity prediction model. Data from 29,057 earthquake waveforms recorded by 293 stations, documenting 9,206 earthquakes in New Zealand (2013-2022), were analyzed, including only seismic records with magnitudes exceeding 3 ($M > 3$) and within 100 km epicentral distance. The non-independence of the data, due to multiple station records per event, posed a challenge. Traditional regression models were inadequate, prompting the adoption of a multilevel model (MLM) with random effects for stations, earthquakes, and time. Initial correlation analysis identified log (Pv) as the best predictor for estimating log (PGV) over other P-wave parameters; Pv and PGV are peak ground velocities of P and S waves, respectively. The necessity of MLM was assessed, revealing significant variance between stations (ICC = 0.459), earthquakes (ICC = 0.610), and years (ICC = 0.162), highlighting the importance of random effects. The MLM significantly improved model fit (conditional R^2 = 0.826, marginal R^2 = 0.718), reducing RMSE and MAPE compared to ordinary regression. The results demonstrate that the MLM provides a better fit and applying this model at the station level can enhance the accuracy of ground-shaking intensity predictions, potentially improving the reliability of warning systems and public safety.

Keywords: *Multi-Level Modeling, Linear Mixed Effect Modeling, S-Wave Intensity Estimation, EEWS*