Shaping Tomorrow's Nephrology: Insight-Driven Kidney Care
KSN 2026 SEOUL, KOREA
The 46th Annual Meeting of the Korean Society of Nephrology
THE KOREAN SOCIETY OF NEPHROLOGY
Jun 11 (Thu) – 14 (Sun), 2026
COEX, Seoul, Korea

Abstract Type : Oral presentation
Abstract Submission No.: A-0363
Abstract Topic : Non-dialysis CKD

Machine Learning-Based Model for Quantifying the Environmental Burden of Chronic Kidney Disease in Indonesia

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Case Study : Chronic kidney disease (CKD), a silent killer, affects over 700,000 individuals in Indonesia, turning it into a substantial national health issue. As a rapidly growing global health burden, air pollution plays an important role in its etiology. This study aims to statistically examine whether and to what extent air pollutant exposure correlates with CKD, to identify high-risk provinces and the most influential drivers. A thorough analytical framework was used, including multi-model machine learning and statistical correlation analyses of Sentinel-5P/TROPOMI satellite-derived air pollutants (NO_2, SO_2, CO, O_3, HCHO, AER_AI, and CH_4) and kidney disease prevalence across 38 Indonesian provinces, with distinct confidence interval methods applied. Statistical analysis showed that all detected pollutants were positively correlated with kidney disease prevalence. The most important driver was O3 (Pearson r = +0.397, p = 0.013; Spearman ρ = +0.384, p = 0.017), with a 95% confidence interval of [+0.089, +0.636], followed by SO2, which showed a strong rank correlation (Spearman rho = 0.357, p = 0.028). Among the prediction models, Support Vector Regression (SVR-RBF) achieved the best predictive performance (R^2=0.556, RMSE=0.036, MAE=0.028), followed by Random Forest (R^2=0.390), though bootstrap confidence intervals were wide across models, reflecting the small province-level sample size (n=38). O_3 as the top predictor (Gini importance=0.213, 95% CI [0.087, 0.408]), followed by AER_AI and SO_2, while the stratified median-split analysis confirmed that provinces with high O_3 exposure had significantly higher mean kidney prevalence (0.193%) compared to low-exposure provinces (0.155%, Mann-Whitney p=0.042), with Lampung recording the highest kidney prevalence (0.30%) and DKI Jakarta recording the highest NO_2 exposure (89.4 μmol/m^2) among all provinces. Chronic exposure indicates an independent environmental risk factor for nephrotoxicity at the population level, and that ecological-level air pollution burden, particularly oxidative stress-inducing pollutants, should be incorporated into CKD surveillance, risk stratification, and public health intervention strategies in Indonesia.

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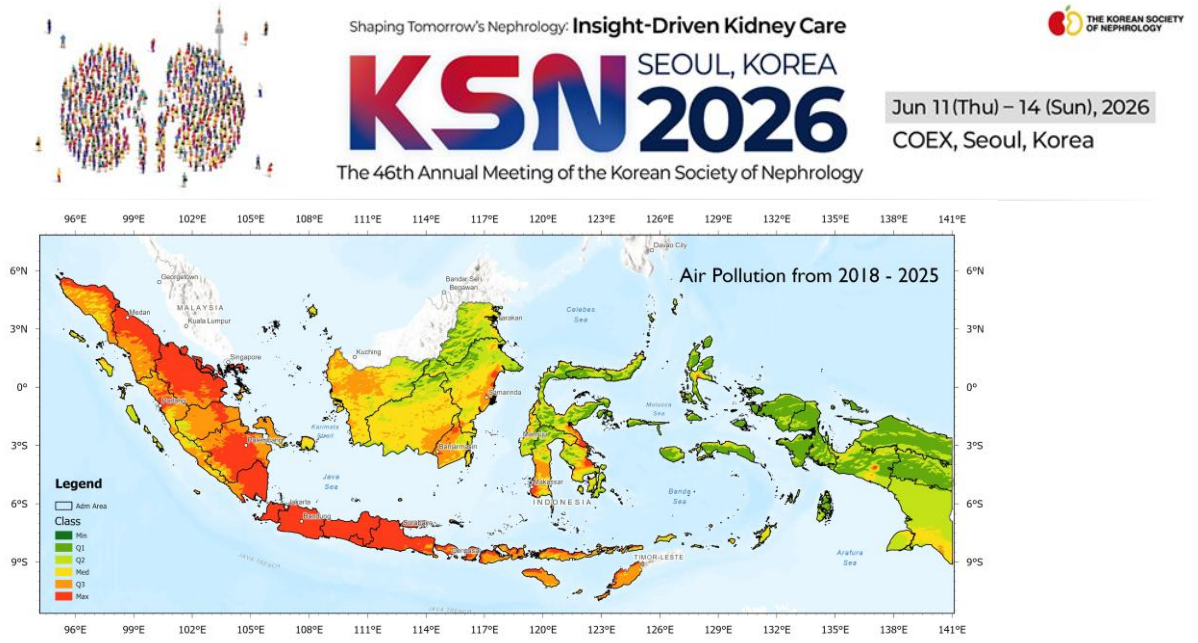

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