A Hybrid Neural Network and Cellular Automata Model for Spatiotemporal Forecasting of PM10 and PM2.5 in Lima, Peru

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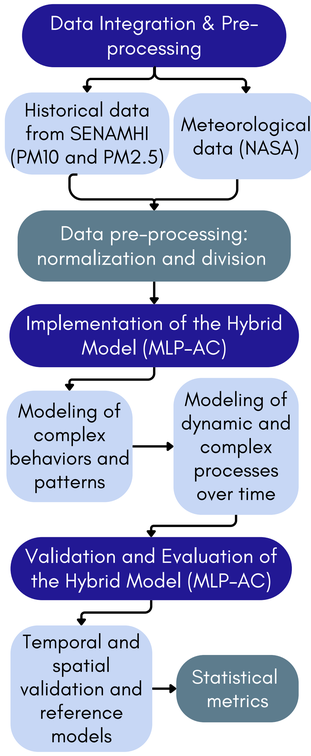
INTRODUCTION

Lima faces severe particulate matter (PM) pollution, exacerbated by complex topography and a lack of accurate forecasting tools. To address this, we developed a novel hybrid model combining a Multilayer Perceptron (MLP) and Cellular Automata (CA) to simulate and forecast PM dispersion, aiming to provide a robust Early Warning System (EWS) to protect public health.

OBJECTIVES

- Propose a hybrid MLP-CA neural model for simulation and forecasting of PM10 and PM2.5 air quality in Metropolitan Lima.
- Characterize spatiotemporal patterns of PM10 and PM2.5 to identify key regional dispersion factors.
- Develop and validate the hybrid MLP-CA architecture, replicating historical dynamics with high fidelity.
- Establish model viability for forecasting and early warning systems for values exceeding ECA limits.

METHODOLOGY



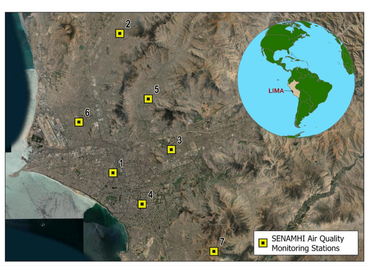


Figure 1. Location of the 7 air quality monitoring stations in Metropolitan Lima (SENAMHI).

ID	Station Name
1	Campo de Marte
2	Carabayllo
3	Santa Anita
4	San Borja
5	San Juan de Lurigancho
6	San Martín de Porres
7	Villa Maria del Triunfo

RESULTS

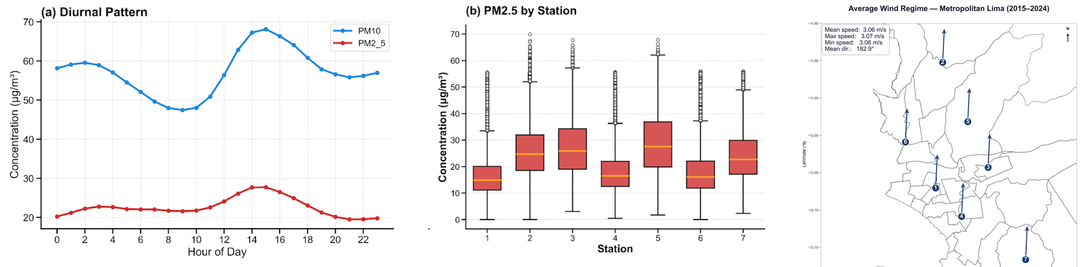


Figure 2. Spatiotemporal Characterization of PM in Lima.

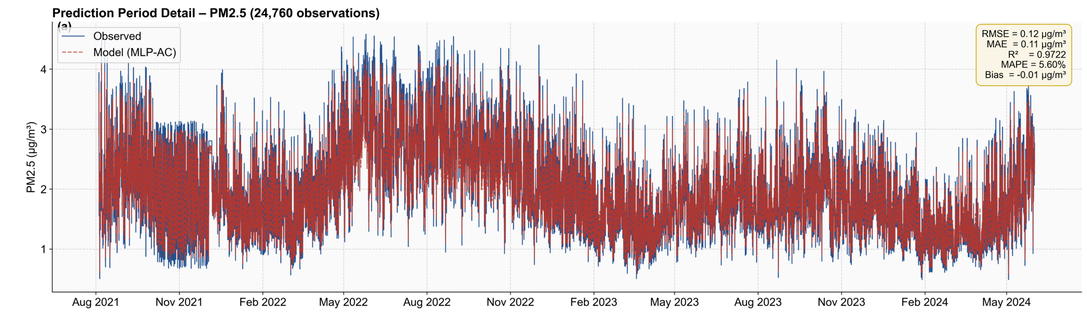


Figure 3. High-Fidelity Temporal Validation (PM2.5).

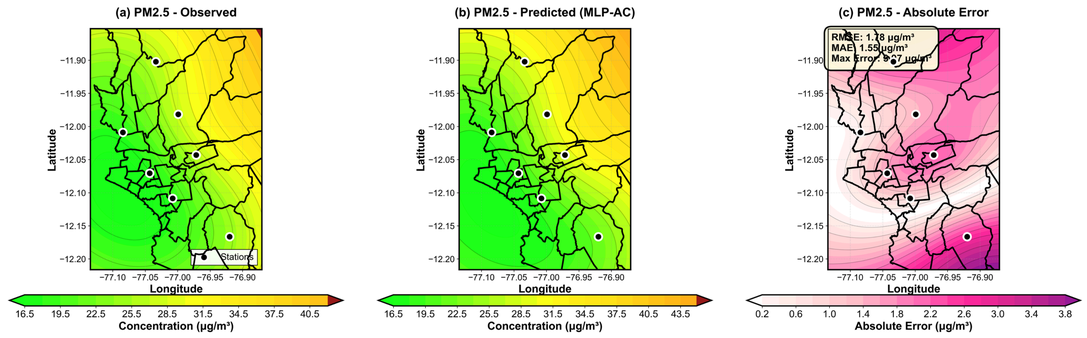


Figure 4. Spatial Validation and PM2.5 Exposure Hotspots.

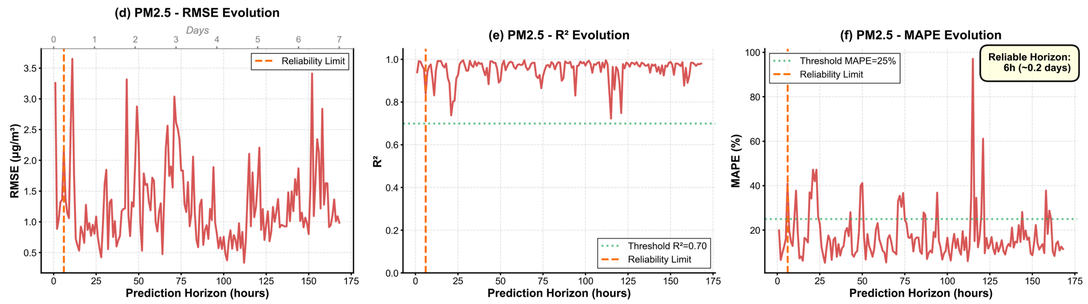


Figure 5. Predictive Horizon and Early Warning Viability.

CONCLUSIONS

- **Identification of Critical Zones:** Confirmed persistent PM hotspots in northern and eastern Lima (Carabayllo, SJL), heavily influenced by topography and vehicular transport patterns.
- **High Model Precision:** The hybrid MLP-CA architecture validated its robustness with exceptional performance (R^2 > 0.97 for PM2.5), effectively replicating non-linear pollutant dynamics.
- **Viability as an Early Warning:** Established a reliable forecast horizon of 6 to 7 hours (MAPE < 25%), proving to be an effective tool for anticipating exceedances of Environmental Quality Standards (ECA-Peru).
- **Support for Policy Making:** The generated high-resolution risk maps provide a robust, data-driven foundation for authorities to implement targeted mitigation strategies and safeguard public health in vulnerable districts.
- ***Note:*** *Full spatiotemporal validation was also successfully conducted for PM10, yielding equally robust forecasting performance (R^2 > 0.96).*

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ABSTRACT

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