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Escuela Técnica Superior de Ingeniería
de Montes, Forestal y del Medio Natural

TÍTULO TESIS: “Air pollution dynamics in arid urban industrial zones for environmental engineering management”

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RESUMEN TESIS DOCTORAL

Air pollution assessment in arid and rapidly urbanizing regions is challenged by complex source interactions, strong meteorological influences, and limited monitoring infrastructure. In Jordan, conventional air quality studies often rely on annual averages and sector-specific analyses, limiting their ability to capture spatiotemporal variability, climate-driven dispersion, and source heterogeneity. This thesis addresses these gaps by advancing a unified, multidisciplinary framework that integrates meteorological analysis, urban and industrial air quality monitoring, wastewater-based indicators, atmospheric dispersion modeling, vehicular emissions modeling, and machine learning techniques to support evidence-based air quality management.

The primary objectives of this research were to: (i) evaluate the impacts of COVID19 lockdown measures on air quality in Amman and Az Zarqa; (ii) assess the heterogeneous effects of seasonal variation and meteorological parameters on PM₁₀ dispersion in major industrial estates; (iii) develop innovative and cost-effective methodologies for forecasting key air pollutants using routinely monitored wastewater parameters; (iv) construct comprehensive emission inventories and dispersion assessments for major wastewater treatment plants (WWTPs); and (v) enhance vehicular emissions modeling frameworks under arid and urban conditions.

Analysis of air quality data from 2018–2023 revealed that COVID-19 lockdown measures resulted in substantial reductions of 60–80% in H₂S, SO₂, and NO₂ and 20–40% in CO and PM₁₀ in Amman and Az Zarqa, primarily driven by decreased traffic volume and industrial activity, with temperature, humidity, and wind speed exerting temporally varying influences on pollutant dispersion. In two major industrial estates: Abdullah II Ibn Al Hussein Industrial Estate and Al Masane' Estate, seasonal and meteorological analyses showed that temperature dominated PM₁₀ variability before the pandemic, combined temperature humidity effects were significant during lockdown periods, and wind speed became the primary dispersion driver post-pandemic, with low wind regimes promoting pollutant accumulation. Seasonal PM₁₀ in Jordan was adjusted using ERA5 wind, iv precipitation, and temperature data via a regression model. Spring showed the highest PM₁₀ from strong winds, summer the lowest from weak winds and high



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temperatures. Adjusted values highlight meteorological effects and help separate them from local emissions, improving seasonal air quality assessment.

The study that develops a cost-effective framework to forecast H_2S and NO_2 at Jordanian wastewater plants using routine effluent parameters, showing strong site- and year-specific correlations (H_2S -COD r up to 0.99; NO_2 - NO_3^- r up to 1.0). Multiple models including MLR, Random Forest, and a hybrid LSTM-XGBoost were tested, with LSTM-XGBoost achieving the highest accuracy ($R^2 > 0.90$ for NO_2 , $R^2 > 0.85$ for H_2S ; RMSE < 1.1 ppb) and capturing seasonal peaks effectively. This approach enables reliable, timely air quality forecasting, reducing reliance on expensive sensors and supporting targeted pollution mitigation strategies. Emission inventory and dispersion modeling of the Al-Baqa'a and As Samra WWTPs (2018–2023) identified extreme H_2S concentrations reaching 177 ppb, significant industrial contributions to ambient SO_2 and NO_2 , methane emissions contributing approximately 1,230 tCO₂e annually, and PM_{2.5} concentrations up to 4.7 times background levels in nearby communities, while mitigation strategies achieved emission reductions of up to 89%.

Enhanced vehicular emissions modeling incorporating climate-responsive silt loading and urban geometry corrections significantly improved prediction accuracy for PM₁₀, PM_{2.5}, CO, and NO_2 along major highways. The US EPA AP-42 and European EEA algorithms were refined using region-specific parameters, including highway geometry, climate-driven dynamic silt loading, and fuel density correction, and applied to two highways in Jordan. The improved models reduced normalized differences by 60–77% for PM₁₀ and PM_{2.5} and by 72% for CO, demonstrating strong gains in predictive accuracy. The framework also captured distinct emission regimes, including a seasonal silt-loading peak of ~ 17.5 g/m² in autumn at the industrial site. Although NO_2 improvements were modest (4–40%) due to complex photochemical processes, the approach proved robust for air quality assessment in arid cities.

This thesis establishes a robust and transferable framework for air pollution assessment, forecasting, and mitigation in arid and climate-sensitive regions. By integrating pandemic-scale natural experiments, industrial meteorological analysis, wastewater-based indicators, advanced dispersion modeling, vehicular emissions modeling, and machine learning, the research provides practical tools and scientific evidence to support targeted air quality management, emissions control, and public health-oriented environmental policymaking in rapidly urbanizing environments.