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Examining Urban Spatio-Temporal of Air Pollution Trend and Sources in Sabah (2019-2024)

Tashnim Hussin[a] & Arnis Asmat[a*]

Structured Abstract

Background: Sabah is currently experiencing a transition towards a rapid urbanisation and industrial expansion, yet its air quality research remains under-represented compared to Peninsular Malaysia. Sabah complex interaction between anthropogenic sources and transboundary haze that is driven by El Niño phenomenon and south-westerly winds. This study addresses the knowledge gap by establishing a comprehensive five-year baseline across diverse geographic locations, from coastal ports to inland valley, using trend analysis, Principal Component Analysis (PCA), and Multiple-Linear Regression (MLR). By decoupling meteorological influences, such as monsoon-driven deposition, from human-led emissions, this research provides the atmospheric evidence needed to develop region-specific environmental policies and protect public health in East Malaysia.

Methods: This study utilized a three-tier statistical framework to comprehensively analyze Sabah's air quality dynamics, moving from observation to source identification and predictive modelling. First, Trend Analysis is employed to detect temporal shift and evaluate the impact of urbanisation and the COVID-19 lockdowns, on pollutant concentration over a five-year period. Next, Principal Component Analysis (PCA) is applied to reduce data dimensionality and perform sources apportionment and effectively isolation meteorological from anthropogenic combustion sources. Finally, Multiple Linear Regression (MLR) is used to quantify the relationship between weather variables and pollutants, providing a forecasting tool to determine the predictive weight of factors like temperature, wind speed, wind direction, relative humidity and solar radiation.

Results: In this study, the Trend Analysis revealed that Sabah's air quality for all pollutants are well below the Malaysian Ambient Air Quality Standards (MAAQS) limits. However, significant temporal fluctuation was observed, particularly during the COVID-19 Movement Control Order (MCO). While most pollutants like NO2 and CO showed a marked decline due dual-influence system, to reduced vehicular mobility, particulates (PM10 and PM2.5) and Ozone (O3), continue to exhibit seasonal spikes. Next, this study shows that Sabah's air quality is governed by a dual-influence system where meteorological as the "Master Regulator" (PC1), and human activity serves as the primary pollution source (PC2). Principal Component Analysis (PCA) identified that atmospheric mixing and solar radiation drive the natural cleansing of the state, while Multiple Linear Regression (MLR) confirms that urban stations like Kota Kinabalu and Tawau is driven by the Ambient Temperature, where intense solar radiation accelerates photochemical reactions to produce high ozone levels (R^2=0.74). In contrast with Keningau and Sandakan, which are driven by Wind Direction and Humidity, which dictate whether particulates are trapped in inland valley or flushed out by coastal breezes.

Conclusion: In this study, it was concluded that Sabah's air quality remains consistently within the Malaysian Ambient Air Quality Standards (MAAQS), and that is governed by a complex interplay

*Correspondence: rnis_annis@uitm.edu.my

[a] School of Chemistry & Environment, Faculty of Applied Sciences, Universiti Teknologi MARA, Shah Alam, Malaysia

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between localized geography and meteorological "Master Regulators". Trend analysis demonstrated that while MCO lockdowns successfully reduced the anthropogenic gases like NO2 and CO, seasonal spikes in PM2.5 and O3 persist due to transboundary haze and solar radiation. PCA and MLR results further refined these findings by identifying distinct regional drivers; Kota Kinabalu and Tawau are influenced by Ambient Temperature, while Keningau and Sandakan are dictated by Wind Direction. Ultimately, these findings serve as a critical atmospheric roadmap for Sabah, highlighting that region-specific policies are necessary to maintain the state's air quality amidst rapid urbanisation and changing climate.

Keywords: Air Quality, Spatio-Temporal Analysis, Principal Component Analysis (PCA), Multiple Linear Regression (MLR)

*Correspondence: rnis_annis@uitm.edu.my

[a] School of Chemistry & Environment, Faculty of Applied Sciences, Universiti Teknologi MARA, Shah Alam, Malaysia