

Maximum Wind Speed, Wind Direction, and Pneumonia Incidence Among Children Under Five: An Ecological Study

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Abstract:

Childhood pneumonia is influenced by interactions among infectious, individual, environmental, and meteorological factors, yet the contribution of wind characteristics to pneumonia occurrence remains insufficiently understood in tropical urban settings. This study examined the relationship between maximum wind speed, wind direction at maximum speed, and pneumonia incidence among children under five in Palangka Raya City, Indonesia, during 2016–2024. An analytical observational ecological design was applied using aggregate secondary data on childhood pneumonia and meteorological parameters. Descriptive analysis characterized temporal and spatial patterns, while linear regression assessed associations between wind parameters and pneumonia incidence. Pneumonia incidence varied substantially over the observation period, reaching its lowest level in 2021, with 22 cases, and its highest in 2024, with 139 cases. Spatial heterogeneity was observed across Community Health Center catchment areas, with a marked increase in Kereng Bangkirai during 2023–2024. Maximum wind speed showed a strong positive association with pneumonia incidence ($\beta = 0.940$, $t = 8.827$, $p < 0.001$), while wind direction at maximum speed also demonstrated a significant association ($\beta = 0.972$, $t = 15.817$, $p < 0.001$). These findings indicate that wind variability may contribute to ecological patterns of childhood pneumonia through atmospheric transport and exposure processes. Causal inference remains limited by the ecological design, unmeasured environmental confounders, and the circular nature of wind-direction data. Future studies should integrate circular statistical methods, air-quality indicators, emission sources, land cover, and spatiotemporal pneumonia data to strengthen environmental risk assessment.

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INTRODUCTION

Pneumonia in children under five remains an important global public health concern because susceptibility to respiratory infection is shaped by interactions among biological vulnerability, infectious agents, environmental conditions, and patterns of exposure (Perin et al., 2022). Young children have developing immune and respiratory systems that may increase their sensitivity to adverse environments (Murphy et al., 2024). Respiratory infections also occur within physical and social settings that influence exposure to infectious agents and environmental hazards (Islam et al., 2024). Meteorological variability, air quality, housing conditions, population density, and human activity can modify these exposure pathways (Adhikary et al., 2024). An environmental health perspective is therefore essential for understanding childhood pneumonia beyond individual clinical risk factors (Ruffles et al., 2024). Recent evidence supports both the continuing importance of lower

respiratory infections in under-five health and the contribution of environmental conditions to childhood respiratory morbidity.

Meteorological conditions are particularly relevant to childhood respiratory health because atmospheric processes influence the transport, dispersion, and concentration of airborne materials (Lee et al., 2023). Temperature, humidity, rainfall, solar radiation, wind speed, and wind direction influence local atmospheric conditions and pollutant concentrations (Nguyen et al., 2024). Wind speed determines the intensity of air-mass movement and can alter the dilution or redistribution of particulates and pollutants (Lin et al., 2024). Wind direction determines the orientation of air movement and may influence the spatial transport of particulate matter toward specific receiving areas (Chen et al., 2024). Variability in these parameters can generate differences in environmental exposure across time and space through interactions among meteorology, wind fields, terrain, and pollutant distribution (Song et al., 2022). Current evidence directly supports the roles of meteorological variability, wind speed, wind direction, and local physical environments in determining pollutant transport and exposure patterns.

Palangka Raya City provides a relevant setting for examining this relationship because it includes urban settlements, open areas, vegetation, diverse human activities, and heterogeneous environmental conditions. Pneumonia incidence among children under five fluctuated markedly during 2016–2024, with substantial declines during 2020–2022 followed by a sharp increase in 2023 and 2024. Spatial differences were also evident across Community Health Center catchment areas. Kereng Bangkirai showed a pronounced increase during the final years of observation, while Pahandut and Menteng displayed different temporal profiles. These variations suggest that local environmental characteristics may contribute to differences in pneumonia occurrence (Qu et al., 2023).

Current environmental epidemiology increasingly recognizes meteorological variables as potential determinants or modifiers of respiratory disease patterns through their effects on atmospheric transport and population exposure (Demoze & Yitageasu, 2025). Previous research has examined relationships between respiratory infections and temperature, humidity, rainfall, seasonal variation, particulate matter, and other air-quality indicators. Wind-related variables have also been incorporated into studies of pollutant dispersion and transport (Cruz et al., 2023). Existing evidence supports a plausible ecological pathway linking emission sources, atmospheric movement, exposure distribution, and susceptible populations. Wind speed and wind direction should therefore be considered as complementary components of atmospheric exposure assessment. Demoze and Yitageasu (2025) specifically demonstrated associations between meteorological factors and childhood pneumonia, while Cruz et al. (2023) showed that regional and local wind circulations substantially influence PM_{2.5} dynamics and aerosol transport.

Important research gaps remain regarding the specific relationship between wind variability and childhood pneumonia in Palangka Raya City. Local evidence integrating pneumonia surveillance with maximum wind speed and wind direction at maximum speed remains limited. Conventional analyses may also oversimplify wind direction because directional data are circular, with 0° and 360° representing the same orientation (Harvey et al., 2024). Linear treatment of directional degrees can consequently produce misleading interpretations when this structure is ignored, supporting the use of analytical approaches specifically designed for circular-linear relationships (Liu & Yan, 2024). The present study addresses this gap by examining both wind parameters within an ecological framework while explicitly recognizing the methodological limitations of linear analysis for directional data. Harvey et al. explicitly demonstrate the special statistical requirements of wind-direction time series, while Liu and Yan provide a contemporary circular-linear modeling framework for directional wind data.

The novelty of this study lies in integrating long-term childhood pneumonia data with wind characteristics to explore temporal and spatial patterns within a local environmental health framework. The analysis covers 2016–2024 and considers aggregate pneumonia incidence across the Community Health Center's working areas alongside meteorological observations. Maximum wind speed represents the intensity of air-mass movement, while the wind direction at maximum speed indicates the potential transport orientation. This combined approach provides a preliminary basis for identifying atmospheric patterns that warrant further investigation using high-resolution air-quality measurements and emission-source characterization (Lung et al., 2025), together with integrated spatiotemporal exposure and health-impact analysis (Bian et al., 2024). These references are particularly appropriate because Lung et al. examined PM exposure sources in Indonesia using high-resolution measurements. At the same time, Bian et al. (2024) demonstrated the value of integrating spatial, temporal, pollution, population, and health information.

The present study aims to analyze the relationship between maximum wind speed and pneumonia incidence among children under five in Palangka Raya City during 2016–2024 and to evaluate the relevance of wind direction at maximum speed within the observed ecological pattern. The study is important because the marked increase in pneumonia cases toward the end of the observation period highlights the need for stronger environmental surveillance and locally relevant risk assessment. A clearer understanding of meteorological associations, when integrated with air-quality data, may support the identification of high-risk periods and areas, particularly because recent pediatric evidence demonstrates important interactions between PM_{2.5} and meteorological conditions in respiratory infection risk (Wang et al., 2025). The findings are expected to provide an empirical foundation for future environmental health research and the development of more comprehensive pneumonia risk models and early-warning approaches, consistent with emerging evidence supporting environmental surveillance as an early-warning strategy for respiratory disease activity (Eren et al., 2024).

METHOD

Design

This study employed an analytical observational design with an ecological approach (ecological study) to examine associations between meteorological parameters and pneumonia incidence at the population level. The analysis relied exclusively on aggregate secondary data collected across the defined observation period, with no direct assessment of individual participants. No intervention, experimental manipulation, or participant recruitment was undertaken, consistent with the non-interventional nature of ecological research.

Setting and Time

The study was conducted in Palangka Raya City, Central Kalimantan Province, Indonesia, which served as the geographical setting for the ecological analysis. The observation period spanned 2016–2024, providing 9 consecutive years of data to assess temporal patterns in childhood pneumonia incidence and meteorological variability. The analytical dataset comprised routinely collected records of pneumonia incidence among children under five, along with corresponding meteorological parameters available throughout the study period.

Population, Sample, and Sampling

The study population comprised all available records of pneumonia incidence among children under five in Palangka Raya City, along with corresponding meteorological data, including wind

speed and wind direction, for the period 2016–2024. The analytical sample included all eligible secondary data, consisting of aggregate pneumonia incidence records from Community Health Center catchment areas and meteorological measurements of maximum wind speed and wind direction recorded at the time of maximum wind speed. A total sampling approach (census/saturated sampling) was used, in which every available data unit that met the predefined inclusion criteria during the study period was included in the analysis. No random or purposive selection of observation units was undertaken, ensuring that the analysis represented the complete set of eligible aggregate data available for the 2016–2024 observation period.

Instruments and Measurement Properties

The study utilized routinely collected secondary datasets as the primary measurement sources, comprising aggregate records of pneumonia incidence among children under five within the catchment areas of Community Health Centers in Palangka Raya City. Meteorological exposure was assessed using the maximum wind speed (ff_x), defined as the highest recorded wind speed during the relevant observation period. Wind direction at the time of maximum wind speed (ddd_x) was included as the directional meteorological parameter used to characterize prevailing airflow conditions associated with each observation.

Data Collection Procedure

Secondary data on acute respiratory infection (ARI)/pneumonia cases among children under five were obtained from the Palangka Raya City Health Office and organized according to Community Health Center catchment areas. Meteorological observations describing wind parameters were compiled for the same observation period spanning 2016–2024. Pneumonia records were subsequently classified by geographical catchment area, Community Health Center, and observation period to ensure consistency between the health and meteorological datasets used in the analysis.

Data Analysis

Descriptive statistics were used to characterize the overall distribution of pneumonia incidence across the study period and geographical units. Inferential analysis employed linear regression to evaluate the associations between wind parameters and pneumonia incidence, with effect estimates reported as the standardized beta coefficient (β), t-value, and p-value. Statistical significance was defined as $p < 0.05$.

Ethical Declaration

Ethical approval was obtained from the Institutional Health Research Ethics Committee before data collection (Approval No. 401.3/0026/DPMPSTP/SKPU/VIII/2026). Informed consent was not required because the study used secondary aggregate data without direct participant recruitment, intervention, or access to identifiable information. Data confidentiality was maintained throughout the study in accordance with the Declaration of Helsinki and applicable research ethics guidelines.

RESULT

Temporal Distribution of Pneumonia

The temporal distribution of pneumonia cases in Palangka Raya City varied substantially between 2016 and 2024. The number of reported cases ranged from 22 cases in 2021 to 139 cases

in 2024. After a decline from 101 cases in 2019 to 27 cases in 2020 and 22 cases in 2021, the number of cases increased to 32 in 2022, 132 in 2023, and 139 in 2024.

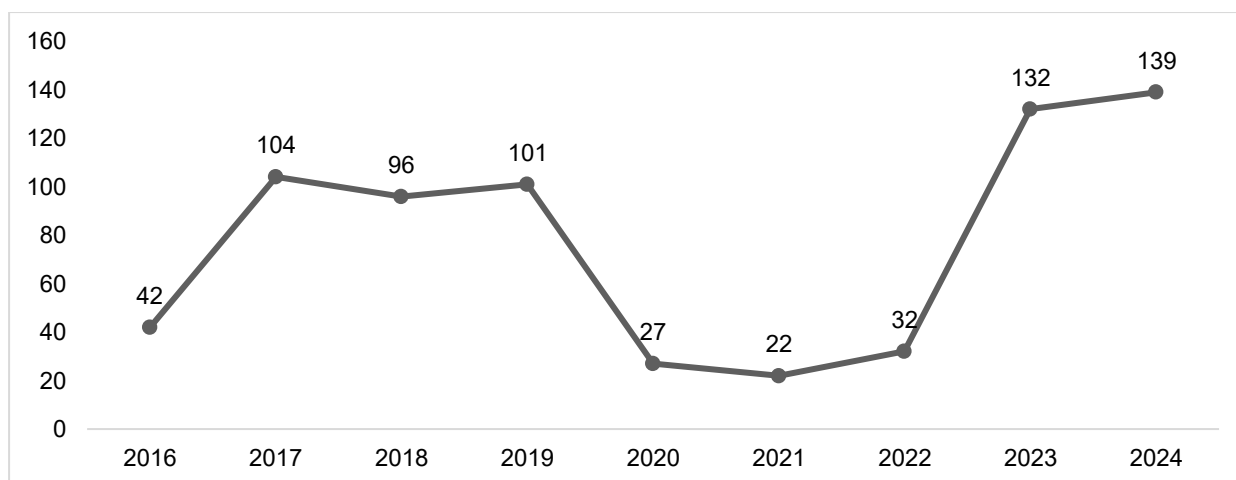


Figure 1. Temporal and Spatial Distribution of Pneumonia Cases in Palangka Raya City, 2016–2024

The temporal pattern demonstrates considerable variation in pneumonia incidence over the study period. Cases increased substantially during 2023–2024 after relatively low numbers during 2020–2022, reaching the highest level observed in 2024 (139 cases).

Spatial Distribution of Pneumonia

The spatial distribution of pneumonia cases also varied across the Community Health Center coverage areas. Pahandut recorded 71 cases in 2019, while Kereng Bangkirai saw cases increase from 32 in 2023 to 66 in 2024. Menteng saw an increase from 8 cases in 2022 to 43 in 2023, then a decrease to 20 in 2024. These findings indicate heterogeneity in the distribution of reported pneumonia cases across geographic areas.

Table 2. Association of Meteorological Factors With Pneumonia Incidence

Meteorological factor	N	Standardized β	t	p
Maximum wind speed (ff_x)	10	0.940	8.827	<0.001
Wind direction at maximum speed (ddd_x)	10	0.972	15.817	<0.001

The findings presented in Table 2 demonstrate that both maximum wind speed and wind direction at maximum speed were positively and significantly associated with pneumonia incidence. Maximum wind speed showed a strong association ($\beta = 0.940$, $t = 8.827$, $p < 0.001$), while wind direction at maximum speed also demonstrated a strong positive association ($\beta = 0.972$, $t = 15.817$, $p < 0.001$). However, these findings should be interpreted cautiously because the regression analysis was based on only 10 observations.

DISCUSSION

The present study identified marked temporal and spatial variation in childhood pneumonia incidence in Palangka Raya City during 2016–2024, accompanied by strong statistical associations with maximum wind speed and wind direction at maximum speed. Pneumonia cases declined during 2020–2022, reached the lowest level in 2021, then increased sharply in 2023 and 2024. Spatial

heterogeneity was also evident across Community Health Center catchment areas, with Kereng Bangkirai showing the most pronounced increase toward the end of the observation period. Maximum wind speed was positively associated with pneumonia incidence ($\beta = 0.940$; $p < 0.001$), and wind direction at maximum speed was also strongly associated ($\beta = 0.972$; $p < 0.001$). These findings indicate that atmospheric variability may be relevant to the ecological distribution of pneumonia, consistent with evidence that meteorological exposures can influence the risk of childhood pneumonia (Lu et al., 2023).

The temporal pattern observed in Palangka Raya is broadly consistent with previous epidemiological research showing that childhood respiratory infections fluctuate in response to environmental, infectious, behavioral, and health-system factors. Studies in tropical settings have reported variation in pneumonia and acute respiratory infection associated with meteorological conditions, pathogen circulation, population mobility, air pollution, and healthcare utilization. The reduction in recorded cases during 2020–2022 warrants caution, as this period coincided with major changes in mobility, healthcare-seeking behavior, infection control, and disease surveillance during the COVID-19 pandemic (Schroeder et al., 2022). The subsequent increase in 2023–2024 may reflect renewed transmission, restored healthcare utilization, improved case detection, changes in environmental exposure, or several processes acting simultaneously; a substantial post-pandemic resurgence of pediatric respiratory infections has also been documented (Winthrop et al., 2024). The available ecological data cannot distinguish among these explanations.

The spatial heterogeneity in pneumonia incidence is consistent with previous research showing that respiratory disease burden is rarely uniformly distributed across geographic areas. Differences in settlement density, housing quality, vegetation, traffic, open burning, and local emission sources can produce distinct exposure environments. Large-scale ecological analyses have demonstrated geographical variation in the burden of pneumonia and respiratory infections, alongside differences in air pollution and meteorological exposures (Choo et al., 2023). The contrasting patterns observed in Kereng Bangkirai, Pahandut, and Menteng suggest that local environmental context may modify the relationship between meteorological conditions and pneumonia occurrence. Wind-related exposure is especially dependent on source–receptor geography because similar wind conditions can have different consequences across locations. Strong winds may dilute pollutants in one area while transporting smoke, dust, or combustion-derived particles toward another, making spatial context essential for interpretation.

The positive association between maximum wind speed and pneumonia incidence is scientifically plausible through mechanisms involving pollutant transport, resuspension, dispersion, and changes in population exposure to airborne material. Atmospheric research shows that wind influences the movement of particulate matter, dust, smoke, bioaerosols, and combustion-related pollutants. Experimental and modeling evidence indicate that increasing wind velocity can promote resuspension and subsequent dispersion of previously deposited particles in urban environments (Banari et al., 2023). Higher wind speed can reduce local pollutant concentrations through dilution under some conditions. However, it can also increase resuspension of road dust and soil particles or transport polluted air masses from surrounding areas. Epidemiological evidence further indicates that both low- and high-wind-speed conditions may influence childhood respiratory morbidity, with effects varying with local meteorological conditions (Yang et al., 2022). The strong positive coefficient in this study should therefore be interpreted as a context-specific association rather than evidence that stronger winds are universally harmful.

The observed relationship between wind conditions and pneumonia is also consistent with broader evidence linking air pollution to respiratory infection in young children. Fine and inhalable particulate matter can induce oxidative stress, airway inflammation, epithelial injury, and

dysregulation of antimicrobial and antiviral immune responses, thereby increasing susceptibility to respiratory infection (Esposito et al., 2025). Young children are particularly vulnerable because their lungs and immune systems are still developing, and their ventilation rate relative to body size can increase the inhaled dose of pollutants. Wind may act as an upstream determinant of exposure by changing where airborne particles are transported or concentrated. The present study did not measure PM_{2.5}, PM₁₀, gaseous pollutants, or pathogen circulation, preventing direct testing of this pathway. The findings are therefore best interpreted as supporting an atmospheric exposure hypothesis that requires confirmation with direct environmental measurements.

The association with wind direction requires especially cautious interpretation because wind direction is a circular variable rather than a conventional linear measure. Values near 0° and 360° represent almost identical directions despite appearing numerically far apart, making ordinary linear regression potentially inappropriate when raw degrees are entered directly into the model. Contemporary methodological work on wind-direction variability emphasizes that directional observations require circular statistical treatment because their periodic structure differs fundamentally from conventional linear variables (Dallas et al., 2024). The reported β of 0.972 should not be interpreted as indicating that progressively larger directional degrees correspond to progressively higher pneumonia incidence. Circular statistics, vector-component transformations, directional distributions, or source-oriented exposure models would provide more appropriate analytical alternatives. A more informative analysis would determine whether specific directional sectors are associated with increased case occurrence and whether those sectors correspond to plausible emission sources or transport pathways.

The combined interpretation of wind speed and wind direction provides a stronger environmental framework than assessing either variable in isolation. Wind speed characterizes the intensity of air movement, whereas wind direction identifies the orientation of transport between potential sources and exposed populations. Atmospheric exposure can be conceptualized as a source–transport–receptor process in which pollutants are emitted, transported under specific wind conditions, dispersed across space, and potentially inhaled by susceptible populations. Computational evidence demonstrates that wind flow, urban morphology, turbulent mixing, and transport pathways jointly determine the spatial dispersion of pollutants across urban environments (Wang et al., 2024). The current findings therefore support development of a spatiotemporal model integrating wind fields, PM_{2.5}, PM₁₀, land cover, settlement density, emission sources, and the spatial distribution of pneumonia cases.

The public health implications of these findings are most relevant to environmental surveillance and area-based risk assessment rather than individual clinical prediction. Routinely available meteorological information could strengthen environmental health monitoring when interpreted together with air-quality indicators and disease surveillance data. Community Health Center areas showing repeated increases in pneumonia under specific atmospheric conditions could be prioritized for environmental assessment, source identification, respiratory surveillance, and targeted preventive communication. Integration of meteorological, pollution, and health data has already demonstrated potential for developing predictive and early-warning models for respiratory health outcomes (Sun et al., 2023). Locally calibrated systems could eventually identify periods when atmospheric conditions favor increased exposure to harmful airborne material, although such applications would require prospective development and external validation.

Several methodological limitations substantially affect the interpretation and generalizability of the findings. The ecological design uses aggregate data and cannot establish whether individual children diagnosed with pneumonia were personally exposed to the wind-related conditions represented in the analysis, creating a risk of ecological fallacy: associations observed at the

population level cannot automatically be transferred to individuals (Shih et al., 2023). The study analyzed case counts rather than population-standardized incidence rates, leaving open the possibility that changes in the number of children under five contributed to temporal or spatial differences. Important confounders were not included, such as temperature, humidity, rainfall, air pollution, wildfire or peatland smoke, housing conditions, nutritional status, vaccination, socioeconomic conditions, healthcare access, pathogen circulation, and reporting practices. The single-city setting further limits transferability to other environmental and healthcare contexts.

The statistical analysis also requires caution because the observation series is small relative to the strength of the reported coefficients. The study period of 2016–2024 represents nine calendar years, while the regression table reports $N = 10$, creating a discrepancy that should be clarified before publication. Linear regression with very few aggregate observations can yield unstable effect estimates and p-values that are sensitive to influential observations. Temporal observations may also violate the independence assumption because adjacent observations can be autocorrelated, a feature that requires explicit statistical accommodation in time-series analyses (Bottomley et al., 2023). Common temporal trends between exposure and outcome can additionally generate misleading or potentially spurious regression relationships when the time-series structure is inadequately addressed (Cummins et al., 2022). Residual diagnostics, assessment of influential observations, testing for temporal autocorrelation, and clarification of the analytical unit are therefore necessary. Higher-frequency daily or monthly data analyzed using time-series or spatiotemporal methods would provide a substantially more robust framework for future research.

CONCLUSION

Childhood pneumonia incidence in Palangka Raya City showed substantial temporal and spatial variability during 2016–2024, with maximum wind speed and wind direction at maximum speed demonstrating strong statistical associations with pneumonia occurrence. These findings support the relevance of meteorological conditions within an environmental health framework, particularly through their potential influence on atmospheric transport, pollutant dispersion, and population exposure. The ecological design, the limited number of aggregate observations, the absence of major environmental and individual-level confounders, and the linear treatment of wind direction restrict causal interpretation and require cautious inference. Future studies should apply higher-resolution spatiotemporal data, circular statistical methods, population-standardized incidence measures, and integrated information on $PM_{2.5}$, PM_{10} , emission sources, land cover, settlement density, and other meteorological factors to clarify the mechanisms underlying observed associations. Such an approach may strengthen environmental surveillance and support the development of locally relevant pneumonia risk assessment and early-warning systems.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interest in the conduct of research, data analysis, or preparation of this article.

REFERENCES

- Adhikary, M., Mal, P., & Saikia, N. (2024). Exploring the link between particulate matter pollution and acute respiratory infection risk in children using generalized estimating equations analysis: A robust statistical approach. *Environmental Health*, 23, 12. <https://doi.org/10.1186/s12940-024-01049-3>
- Banari, A., Hertel, D., Schlink, U., Hampel, U., & Lecrivain, G. (2023). Simulation of particle resuspension by wind in an urban system. *Environmental Fluid Mechanics*, 23, 41–63. <https://doi.org/10.1007/s10652-022-09905-x>
- Bian, Z., Ren, C., Wang, D., & Cao, S.-J. (2024). Spatial-temporal analysis of urban air pollution related exposure and health impacts: Driving human-centered regulation and control. *Urban Climate*, 58, 102161. <https://doi.org/10.1016/j.uclim.2024.102161>
- Bottomley, C., Ooko, M., Gasparrini, A., & Keogh, R. H. (2023). In praise of Prais-Winsten: An evaluation of methods used to account for autocorrelation in interrupted time series. *Statistics in Medicine*, 42(8), 1277–1288. <https://doi.org/10.1002/sim.9669>
- Chen, X., He, J., Han, M., Li, X., Xu, R., Ma, H., Wang, X., Wu, X., & Kumar, P. (2024). Understanding the impacts of street greening patterns and wind directions on the dispersion of fine particles. *Science of the Total Environment*, 953, 176044. <https://doi.org/10.1016/j.scitotenv.2024.176044>
- Choo, E. L. W., Janhavi, A., Koo, J. R., Yim, S. H. L., Dickens, B. L., & Lim, J. T. (2023). Association between ambient air pollutants and upper respiratory tract infection and pneumonia disease burden in Thailand from 2000 to 2022: A high frequency ecological analysis. *BMC Infectious Diseases*, 23, 379. <https://doi.org/10.1186/s12879-023-08185-0>
- Cruz, M. T., Simpas, J. B., Sorooshian, A., Betito, G., Cambaliza, M. O. L., Collado, J. T., Eloranta, E. W., Holz, R., Topacio, X. G. V., Del Socorro, J., & Bagtasa, G. (2023). Impacts of regional wind circulations on aerosol pollution and planetary boundary layer structure in Metro Manila, Philippines. *Atmospheric Environment*, 293, 119455. <https://doi.org/10.1016/j.atmosenv.2022.119455>
- Cummins, D. P., Stephenson, D. B., & Stott, P. A. (2022). Could detection and attribution of climate change trends be spurious regression? *Climate Dynamics*, 59(9–10), 2785–2799. <https://doi.org/10.1007/s00382-022-06242-z>
- Dallas, S., Stock, A., & Hart, E. (2024). Control-oriented modelling of wind direction variability. *Wind Energy Science*, 9(4), 841–867. <https://doi.org/10.5194/wes-9-841-2024>
- Demoze, L., & Yitageasu, G. (2025). Association of meteorological factors with childhood pneumonia incidence in Central Gondar Zone, Northwest Ethiopia: A time-series study (2013–2022). *Italian Journal of Pediatrics*, 51, 225. <https://doi.org/10.1186/s13052-025-02072-x>
- Eren, Z. B., Vatansever, C., Kabadayı, B., Haykar, B., Kuloğlu, Z. E., Ay, S., Nurlybayeva, K., Eyikudamaci, G., Barlas, T., Palaoğlu, E., Beşli, Y., Kuşkucu, M. A., Ergönül, Ö., & Can, F. (2024). Surveillance of respiratory viruses by aerosol screening in indoor air as an early warning system for epidemics. *Environmental Microbiology Reports*, 16(4), e13303. <https://doi.org/10.1111/1758-2229.13303>
- Esposito, S., Fainardi, V., Titolo, A., Lazzara, A., Menzella, M., Campana, B., Argentiero, A., & Principi, N. (2025). How air pollution fuels respiratory infections in children: Current insights. *Frontiers in Public Health*, 13, 1567206. <https://doi.org/10.3389/fpubh.2025.1567206>
- Harvey, A., Hurn, S., Palumbo, D., & Thiele, S. (2024). Modelling circular time series. *Journal of Econometrics*, 239(1), 105450. <https://doi.org/10.1016/j.jeconom.2023.02.016>

- Islam, M., Islam, K., Dalal, K., & Hawlader, M. D. H. (2024). In-house environmental factors and childhood acute respiratory infections in under-five children: A hospital-based matched case-control study in Bangladesh. *BMC Pediatrics*, 24, 38. <https://doi.org/10.1186/s12887-024-04525-4>
- Lee, M. H., Mailepessov, D., Yahya, K., Loo, L. H., Maiwald, M., & Aik, J. (2023). Air quality, meteorological variability and pediatric respiratory syncytial virus infections in Singapore. *Scientific Reports*, 13, 1001. <https://doi.org/10.1038/s41598-022-26184-0>
- Lin, X., Fu, Y., Peng, D. Z., Liu, C.-H., Chu, M., Chen, Z., Yang, F., Tse, T. K. T., Li, C. Y., & Feng, X. (2024). CFD- and BPNN-based investigation and prediction of air pollutant dispersion in urban environment. *Sustainable Cities and Society*, 100, 105029. <https://doi.org/10.1016/j.scs.2023.105029>
- Liu, J., & Yan, Z. (2024). A circular-linear probabilistic model based on nonparametric copula with applications to directional wind energy assessment. *Entropy*, 26(6), 487. <https://doi.org/10.3390/e26060487>
- Lu, C., Yang, W., Lan, M., Li, B., & Wang, F. (2023). Effects of intrauterine and postnatal exposure to meteorological factors on childhood pneumonia. *Building and Environment*, 244, 110800. <https://doi.org/10.1016/j.buildenv.2023.110800>
- Lung, S.-C. C., Tsou, M.-C. M., Cheng, C.-H. C., & Setyawati, W. (2025). Peaks, sources, and immediate health impacts of PM_{2.5} and PM₁ exposure in Indonesia and Taiwan with microsensors. *Journal of Exposure Science & Environmental Epidemiology*, 35, 264–277. <https://doi.org/10.1038/s41370-024-00689-4>
- Murphy, J., Tharumakunarah, R., Holden, K. A., King, C., Lee, A. R., Rose, K., Hawcutt, D. B., & Sinha, I. P. (2024). Impact of indoor environment on children's pulmonary health. *Expert Review of Respiratory Medicine*, 17(12), 1249–1259. <https://doi.org/10.1080/17476348.2024.2307561>
- Nguyen, G. T. H., La, L. T., Hoang-Cong, H., & Le, A. H. (2024). An exploration of meteorological effects on PM_{2.5} air quality in several provinces and cities in Vietnam. *Journal of Environmental Sciences*, 145, 139–151. <https://doi.org/10.1016/j.jes.2023.07.020>
- Perin, J., Mulick, A., Yeung, D., Villavicencio, F., Lopez, G., Strong, K. L., Prieto-Merino, D., Cousens, S., Black, R. E., & Liu, L. (2022). Global, regional, and national causes of under-5 mortality in 2000–19: An updated systematic analysis with implications for the Sustainable Development Goals. *The Lancet Child & Adolescent Health*, 6(2), 106–115. [https://doi.org/10.1016/S2352-4642\(21\)00311-4](https://doi.org/10.1016/S2352-4642(21)00311-4)
- Qu, F., Weschler, L. B., Zhang, Y., & Spengler, J. D. (2023). Childhood pneumonia in Beijing: Associations and interactions among selected demographic and environmental factors. *Environmental Research*, 231, 116211. <https://doi.org/10.1016/j.envres.2023.116211>
- Ruffles, T., Inglis, S. K., Memon, A., Seddon, P., Basu, K., Bremner, S. A., Rabe, H., Tavendale, R., Palmer, C. N. A., Mukhopadhyay, S., & Fidler, K. J. (2024). Environmental risk factors for respiratory infection and wheeze in young children: A multicentre birth cohort study. *Pediatric Pulmonology*, 59(1), 19–30. <https://doi.org/10.1002/ppul.26664>
- Schroeder, A. R., Dahlen, A., Purington, N., Alvarez, F., Brooks, R., Destino, L., Madduri, G., Wang, M., & Coon, E. R. (2022). Healthcare utilization in children across the care continuum during the COVID-19 pandemic. *PLOS ONE*, 17(10), e0276461. <https://doi.org/10.1371/journal.pone.0276461>
- Shih, Y. C. T., Bradley, C., & Yabroff, K. R. (2023). Ecological and individualistic fallacies in health disparities research. *JNCI: Journal of the National Cancer Institute*, 115(5), 488–491. <https://doi.org/10.1093/jnci/djad047>
- Song, Z., Chen, B., & Huang, J. (2022). Combining Himawari-8 AOD and deep forest model to obtain city-level distribution of PM_{2.5} in China. *Environmental Pollution*, 297, 118826. <https://doi.org/10.1016/j.envpol.2022.118826>

- Sun, H., Chen, S., Li, X., Cheng, L., Luo, Y., & Xie, L. (2023). Prediction and early warning model of mixed exposure to air pollution and meteorological factors on death of respiratory diseases based on machine learning. *Environmental Science and Pollution Research*, 30(18), 53754–53766. <https://doi.org/10.1007/s11356-023-26017-1>
- Wang, F., Huang, W., Shi, F., Li, Y., Li, Y., Zhang, Q., Shang, Y., Chen, N., Xu, W., & Cheng, Q. (2025). Critical exposure windows of PM_{2.5}-meteorological interactions triggering pediatric *Mycoplasma pneumoniae* epidemics: An age-stratified distributed lag nonlinear modeling approach. *Journal of Environmental Management*, 391, 126533. <https://doi.org/10.1016/j.jenvman.2025.126533>
- Wang, S., Zheng, X., Wang, J., & Yang, J. (2024). Numerical study on the gaseous radioactive pollutant dispersion in urban area from the upstream wind: Impact of the urban morphology. *Nuclear Engineering and Technology*, 56(6), 2039–2049. <https://doi.org/10.1016/j.net.2024.01.011>
- Winthrop, Z. A., Perez, J. M., Staffa, S. J., McManus, M. L., & Duvall, M. G. (2024). Pediatric respiratory syncytial virus hospitalizations and respiratory support after the COVID-19 pandemic. *JAMA Network Open*, 7(6), e2416852. <https://doi.org/10.1001/jamanetworkopen.2024.16852>
- Yang, Z., Li, C., Wang, C., Nie, Y., Zhang, Y., Tian, M., & Zhang, L. (2022). Assessing the impact of meteorological conditions on outpatient visits for childhood respiratory diseases in Urumqi, China. *Journal of Occupational and Environmental Medicine*, 64(10), e598–e605. <https://doi.org/10.1097/JOM.0000000000002640>