The impact of climate variability on pneumonia and tuberculosis incidence: A case study in Surakarta

Nurhassan Agung Prabowo[1*], *Tonang Dwi* Ardyanto[2], *Risalina* Myrtha[3], *Hendrastutik* Apriningsih[4], *Frieska* Dyanneza[5], *Niken Dyah Aryani* Kuncorowati[6], *Novianto Adi* Nugroho[7], *Adji* Suwandono[7], *Maria Galuh Kamenyangan* Sari[8], *Laily* Shofiyah[1], *Nurbaiti* Andiyani[1], and *Narulita Brillianti Fajariani* Putri[1]

[1]Department of Internal Medicine, Faculty of Medicine, Universitas Sebelas Maret
[2]Department of Clinical Pathology, Faculty of Medicine, Universitas Sebelas Maret
[3]Department of Cardiology and Vascular Medicine, Faculty of Medicine, Universitas Sebelas Maret
[4]Department of Pulmonology and Respiratory Medicine, Faculty of Medicine, Universitas Sebelas Maret
[5]Medical Doctor Profession Program, Faculty of Medicine, Universitas Sebelas Maret
[6]Department of Otorhinolaryngology-Head and Neck Surgery, Faculty of Medicine, Universitas Sebelas Maret
[7]Department of Forensic, Universitas Sebelas Maret Hospital, Jl. Ahmad Yani No. 200, Makamhaji, Kartasura, Sukoharjo, Central Java, 57161, Indonesia
[8]Department of Paediatrics, Faculty of Medicine, Universitas Sebelas Maret

Abstract. The impact of changing weather patterns on respiratory diseases is an urgent public health issue, especially in Surakarta. Global climate change poses a serious threat to public health. This study aims to investigate the relationship between annual pneumonia and tuberculosis (TB) incidence and meteorological variables in Surakarta, Central Java province, Indonesia. The methodology of this study uses public data from 2022 to 2024 to compare the incidence of disease cases data, annual rainfall, rainy days, average temperature, and humidity A descriptive-analytical study utilizing a correlational approach was employed to compare the trend of each climate variable with the trend of disease cases across the two years to establish a positive or negative correlation. The incidence of pneumonia spikes (from 233 to 520) directly reflects the shift from a very dry 2022 to much wetter conditions in 2023 and 2024. Conversely, Tuberculosis cases continue to increase every year (from 786 to 1,054) suggesting that non-climatic factors remain the main drivers of the spread of TB. Our findings indicate that the burden of pneumonia is highly sensitive to extreme weather. It highlights the apparent need to integrate climate forecasting into public health surveillance to anticipate better and prepare for outbreaks of Pneumonia.

* Corresponding author: dr.nurhasan21@staff.uns.ac.id

1 Introduction

Global climate change poses a significant threat to public health, particularly through its influence on infectious disease dynamics. Climate fluctuations and ecological shifts, such as changes in seasonal patterns and the rising intensity of climatic extremes (e.g., storms, droughts), have already impacted the epidemiology of various infectious diseases [1,2]. Consequently, health systems must address the new challenges posed by environmental determinants that affect the burden of existing illnesses [1,3].

Respiratory infections are notably sensitive to environmental changes. The environment significantly influences pathogen transmission, including under varying weather conditions. Research indicates that air temperature and humidity can directly impact the survival and transmission of various pathogens [4,5]. Heavy rainfall can indirectly affect public health; flooding may disrupt sanitation systems and force communities into crowded indoor shelters, which creates ideal conditions for disease spread [6,7].

This research focuses on pneumonia and tuberculosis (TB), two leading respiratory diseases that exhibit different behavior patterns. Pneumonia is acute and demonstrated to have seasonal fluctuations highly sensitive to short-term weather variations [4,8]. In contrast, TB is a chronic disease that is primarily influenced by socioeconomic factors such as housing density, nutrition, and indoor ventilation [9,10]. However, climate-driven behaviors—like increased indoor time during prolonged rainy seasons—could alter TB transmission dynamics [2,10].

Although numerous studies have linked climate with respiratory illnesses, much of this research has been conducted in subtropical four-season countries [4,11]. There is a substantial knowledge gap regarding these dynamics in densely populated tropical cities, and limited research has examined both acute (pneumonia) and chronic (TB) diseases in a single urban population. The case of Surakarta, known for its wet and dry seasons and rich health data, offers a suitable context for such an analysis [1,12].

Thus, we aim to analyze relationships between annual rainfall, the number of rainy days, average temperature, humidity, and meteorological conditions in Surakarta for pneumonia and TB incidence trends from 2022 to 2024. This evaluation intends to provide public health officials with insights to enhance early warning systems for respiratory infectious diseases [3,12]. Environmental changes significantly impact respiratory infections, and basic weather factors play a crucial role in pathogen transmission, as evidenced by the relationship between extreme rainfall and increased pneumonia cases [2,4].

2 Methods

The study was devised as a descriptive-analytical study utilizing a correlational approach. This analysis specifically centered on climate variability and the burden of respiratory diseases based on secondary data from Surakarta, Indonesia. Data collection spans 1 January 2022 through 31 December 2024. We apply two categories of public data, both obtained from the Central Statistics Agency (BPS) of Surakarta City. The initial collection was for public health data, like the annual report on Pneumonia and Pulmonary Tuberculosis (TB) occurrence. The second data consists of meteorological information from BMKG. The data has been arranged for analysis in a systematic way. We had four independent climate variables, including total annual precipitation (mm), number of wet days (days), average annual air temperature (°C), and mean annual humidity (%). For comparability, meteorological data (which was previously reported monthly) is consolidated into annual amounts. Annual precipitation and wet days are reported per year, while average temperature and humidity are computed per year. A descriptive analysis was conducted by comparing the trend of each climate variable with the trend of disease cases, using a visual analysis between

the two years. This is used to establish a positive or negative correlation. Because this study employed just publicly available aggregated data and did not use any specific patient identifiers, a formal ethical assessment was not needed.

3 Results

Based on comparative public health data through 2024, two trends in respiratory disease incidence are identified, outlined in Table 1. There were 233 pneumonia cases in 2022, compared with 473 cases recorded as of 2023, a tripling. It was followed by a much quicker increase to 520 cases in 2024. At the same time, however, pulmonary tuberculosis (TB) continued to rise every year. Reported tuberculosis cases went from 786 in 2022 to 892 in 2023 and to 1,054 in 2024. During the same three-year period, accumulated meteorological data show the extent of annual variability, particularly in precipitation. In 2022, a drought hit the country within the seasonal precipitation regimes, resulting in a total of 130.00 mm of annual precipitation. It experienced drastic transformations into very wet conditions: aggregate precipitation increased to 1,743.40 mm in 2023 and 2,459.60 mm in 2024. Importantly, the number of days is, on average, very dry, with a substantial difference in the number of wet-day occurrences across different trends. In 2022, the driest year, there were the most rainy days (195), and in 2023 and 2024, the wettest years, there were the fewest rainy days (116 and 108, respectively). The mean temperature is increasing at every point in time, with temperatures of 26.85°C in 2022, 27.54°C in 2023, and 27.68°C by 2024, regardless of concentration.

A significant temporal relationship between rainfall and pneumonia occurrence was observed. The minimum incidence of pneumonia (233 cases) occurred in the driest year, 2022. Consequently, this large increase in pneumonia incidence (to 473 and 520 cases) was directly proportional to the number of years with heavy rainfall. A strong association with TB is not observed. In contrast, a steady, linear increase in tuberculosis case rates and the substantial variation in rainfall can hardly be compared with the vast variation in precipitation. Moreover, other climatic factors did not reveal a clear direct relationship with the rise in pneumonia cases. As for the year with the most pronounced rise of pneumonia cases (2023), the minimum mean per capita humidity (72.83%) and the maximum mean temperature were the same.

Table 1. Annual Disease Incidence and Aggregated Climate Variables in Surakarta (2022-2024)

Variable	2022	2023	2024
Disease Incidence			
Pneumonia Cases	233	473	520
Tuberculosis (TB) Cases	786	892	1,054
Climate Variables			
Total Annual Rainfall (mm)	130.00	1,743.40	2,459.60
Total Rainy Days (days)	195	116	108
Average Air Temperature (°C)	26.85	27.54	27.68
Average humidity (%)	79.58	72.83	76.33

4 Discussion

The relationship between pneumonia and tuberculosis (TB) incidence and climate variability during the 2022-2024 period shows significant differences in Surakarta. Our main finding

revealed a strong, positive association between extreme annual precipitation and pneumonia, but not with tuberculosis.

There were dramatic increases in the number of pneumonia cases, which more than doubled between 2022 and 2023, closely correlating with the transition from a dry year to a year of heavy rainfall. Pneumonia outbreaks in urban tropical settings are thus acutely sensitive to changes in weather [4,8]. The mechanism must be complex. Heavy rain often triggers localized flooding, in addition to the adverse effect it can have on both sanitation and water quality. In addition, prolonged rainy seasons that force individuals to stay inside lead to overcrowding and poorly ventilated spaces, promoting the transmission of respiratory infections [2,4].

While the number of wet days (195) was recorded as higher in 2022, the corresponding rainfall volume (130 mm) and the number of pneumonia cases (233) were the lowest in the study period. Conversely, the years 2023 and 2024 experienced considerably fewer rainy days but saw significantly higher total rainfall volumes. This pattern suggests that in addition to the simple frequency of rain, the intensity of precipitation (i.e., high total volume) is a more critical factor in increasing the risk of respiratory disease, aligning with findings that heavy rainfall intensity exacerbates disease risk [8,13].

Paradoxically, the absence of association with humidity is notable. In specific laboratory investigations, higher humidity promoted the viability of pathogens [4,5]. However, our results reveal that 2023, which saw the highest number of pneumonia cases, had the lowest average annual humidity, at 72.83%. Such an imbalance suggests that any immediate effects of moisture might be overshadowed by the indirect (but large-scale) social consequences of severe rain, such as increases in indoor congestion. It could also be a limiting factor to annual average humidity, potentially masking severe short-term moisture peaks, especially under heavy rain [2,6].

Equally revealing is the lack of association between climate variables and tuberculosis incidence. TB incidence is steadily increasing and in an unbroken pattern, regardless of whether the year was dry (2022) or excessively wet (2023-2024). These data strongly confirm that tuberculosis transmission is mainly the product of chronic non-climate factors. This finding is consistent with research in other sectors of Central Java. A study examining cropping patterns across the volcanic topo sequence of Central Java found that despite a consistent decrease in annual rainfall over three decades, farmers' actual cropping patterns correlated more strongly with land suitability and irrigation infrastructure, demonstrating the system's adaptation driven by non-climatic factors to rainfall variability [13]. Tuberculosis is a chronic medical condition with a long latency time and is therefore insensitive to short-term meteorological disturbances. Because of its more systematic development, the increasing rate in Surakarta is likely to result from programmatic factors (improved identification and recognition of cases by public health sectors). In contrast, its rise might reflect social factors (dynamic changes in population density or indoor living conditions) rather than an environmental stimulus [14].

The complexity of environmental influence can also be observed in soil studies. Research on the functional diversity of bacteria in saline soils on the Sialang Buah Coast demonstrated that nutrient availability and microbial activity are highly influenced by local soil characteristics, such as salinity and pH, rather than solely by macro-climatic changes [15]. This highlights the importance of considering specific micro-environmental factors in determining biological outcomes.

Several limitations are relevant to consider for this study. One, ecological research relies on aggregated urban-level data, limiting the examination of individual-level risk or causation —a phenomenon known as the ecological fallacy. The three years are not long enough to study long-term trends in climate change; instead, they represent the annual cycles of weather. Third, the missing monthly values are derived from the aggregate year-over-year

precipitation data, which affects overall accuracy. This analysis ultimately failed to account for significant confounding variables, such as air pollution (e.g., PM2.5 concentrations), population vaccination status (e.g., pneumococcal conjugate vaccines), and changes in healthcare-seeking behavior, all of which substantially influence respiratory illness rates.

Because serious weather events are directly related to outbreaks of pneumonia, the strong connection between heavy precipitation and increased pneumonia cases offers good support for integrating windstorm events with public health monitoring. Additionally, the correlation between the severity of rainfall conditions and pneumonia incidence was significant and positive, confirming the association between heavy rainfall and higher rates of pneumonia. For instance, in Surakarta, an excessive amount of forecasted rainfall can also serve as a critical notice to activate clinics, stock medical supplies, or issue public advisories to counter the increase in potential occurrence of acute respiratory diseases. However, in terms of TB control, the statistics show that programs and programmes that alleviate tuberculosis burden can be prioritized to be the main determinant of TB burden, regardless of seasonal weather variation, including: (1) case detection, (2) contact tracing, and (3) cleanliness in indoor living spaces.

5 Conclusion

Based on three-year studies in Surakarta, we found that when local climate variability is involved, responses are different between pneumonia and tuberculosis. This marked increase in pneumonia cases is directly related to the transition from arid years to subsequent years of excessive rainfall in the same area, suggesting local-temporal susceptibility to the disease driven by meteorological conditions. On the other hand, tuberculosis is still very high and has completely resisted these dramatic environmental changes, suggesting that the underlying factors are primarily social and programmatic. The key differences emphasise the importance of a practical perspective: public health surveillance in Surakarta will be significantly enriched by heavy rainfall projections in anticipation and preparation for an increase in pneumonia cases. In summary, tuberculosis control actions should focus on non-clinical interventions, such as case identification and contact tracing.

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References

1. H. Rumbiak, The Impact of Climate Change on the Spread of Environment-Based Infectious Diseases. Journal of Health, Medicine and Nursing. **2**, 1 (2025). https://doi.org/10.59613/jhmn.v2i1.2
2. A. H. Sajib, S. Akter, G. Saha, and Z. Hossain, Demographic-environmental effect on dengue outbreaks in 11 countries. PLOS ONE. **19**, 9 (2024). https://doi.org/10.1371/journal.pone.0305854
3. C.-Y. Kuo, W.-W. Yang, and E. C.-Y. Su, Improving dengue fever predictions in Taiwan based on feature selection and random forests. BMC Infectious Diseases. **24**, S2 (2024). https://doi.org/10.1186/s12879-024-09220-4
4. S. J. Coates, M. D. P. Davis, and L. K. Andersen, Temperature and humidity affect the incidence of hand, foot, and mouth disease: a systematic review of the literature

– a report from the International Society of Dermatology Climate Change Committee. International Journal of Dermatology. **58**, 4 (2019). https://doi.org/10.1111/ijd.14188

5. G. C. Monamele, M.-A. Vernet, R. F. J. Nsaibirni, J. J. R. Bigna, S. Kenmoe, M. R. Njankouo, and R. Njouom, Associations between meteorological parameters and influenza activity in a subtropical country: Case of five sentinel sites in Yaoundé-Cameroon. PLOS ONE. **12**, 10 (2017). https://doi.org/10.1371/journal.pone.0186914
6. A. N. Fadilla, D. Husada, and B. Utomo, Epidemiology of children with severe dengue infection in Dr. Soetomo General Hospital. Journal Of The Indonesian Medical Association—Majalah Kedokteran Indnesia. **70**, 4 (2020)
7. F. Haque, F. C. Lampe, S. Hajat, K. Stavrianaki, S. M. T. Hasan, A. S. G. Faruque, T. Ahmed, S. Jubayer, and I. Kelman, Impacts of climate change on diarrhoeal disease hospitalisations: How does the global warming targets of 1.5–2°C affect Dhaka, Bangladesh? PLOS Neglected Tropical Diseases. **18**, 9 (2024). https://doi.org/10.1371/journal.pntd.0012139
8. J. Cheng, H. Bambrick, L. Yakob, G. Devine, F. D. Frentiu, D. T. T. Toan, P. Q. Thai, Z. Xu, and W. Hu, Heatwaves and dengue outbreaks in Hanoi, Vietnam: New evidence on early warning. PLOS Neglected Tropical Diseases. **14**, 1 (2020). https://doi.org/10.1371/journal.pntd.0007997
9. K. A. Alene, Z. Xu, L. Bai, H. Yi, Y. Tan, D. Gray, K. Viney, and A. C. Clements, Spatial clustering of drug-resistant tuberculosis in Hunan province, China: an ecological study. BMJ Open. **11**, 4 (2021). https://doi.org/10.1136/bmjopen-2020-043685
10. M. A. Kuddus, E. S. McBryde, and O. A. Adegboye, Delay effect and burden of weather-related tuberculosis cases in Rajshahi province, Bangladesh, 2007–2012. Scientific Reports. **9**, 1 (2019). https://doi.org/10.1038/s41598-019-49135-8
11. J. P. Messina, O. J. Brady, N. Golding, M. U. G. Kraemer, G. R. W. Wint, S. E. Ray, D. M. Pigott, F. M. Shearer, K. Johnson, L. Earl, L. B. Marczak, S. Shirude, N. Davis Weaver, M. Gilbert, R. Velayudhan, P. Jones, T. Jaenisch, T. W. Scott, R. C. Reiner, and S. I. Hay, The current and future global distribution and population at risk of dengue. Nature Microbiology. **4**, 9 (2019). https://doi.org/10.1038/s41564-019-0476-8
12. A. J. DePina, A. J. B. Andrade, A. K. Dia, A. L. Moreira, U. D. Furtado, H. Baptista, O. Faye, I. Seck, and E. H. A. Niang, Spatiotemporal characterisation and risk factor analysis of malaria outbreak in Cabo Verde in 2017. Tropical Medicine and Health. **47**, 1 (2019). https://doi.org/10.1186/s41182-018-0127-4
13. S. Sumani, K. Komariah, S. Suntoro, M. Mujiyo, and H. Ullah, Rainfall, drought, and irrigation in relation to crop patterns in the volcanic topo sequence of Central Java, Indonesia. SAINS TANAH - Journal of Soil Science and Agroclimatology. **22**, 1 (2025). https://doi.org/10.20961/stjssa.v22i1.87786
14. Z. Shi, J. Peng, X. Liu, X. Fu, L. Zou, Q. Chen, T. Huang, Y. Zhou, H. Zhu, Y. Wang, S. Tang, and G. Wu, Mycobacterium Tuberculosis Infection Status and Risk Factors Among Household Close Contacts of Rifampicin-Resistant Pulmonary Tuberculosis Patients: A Single-Center Cross-Sectional Study. (2025). https://doi.org/10.2139/ssrn.5186762
15. M. Sembiring, J. M. Hutahuruk, D. N. Susilowati, E. Yuniarti, T. Sabrina, and L. A. M. Siregar, Functional diversity of bacteria in various saline soil plant vegetations

around Sialang Buah Coast, North Sumatra, Indonesia. SAINS TANAH - Journal of Soil Science and Agroclimatology. **21**, 2 (2024). https://doi.org/10.20961/stjssa.v21i2.80075