

A COMPARATIVE ANALYSIS OF INTER-REGIONAL AIR POLLUTION TRENDS IN SRI LANKA

U.S.N. Wickramasinghe^{1*}, S.M. Imbulana¹, J.M.A. Manatunge¹

¹ Department of Civil Engineering, University of Moratuwa, Moratuwa, Sri Lanka

**Corresponding author: sandaranw@gmail.com*

Abstract

Air pollution is a major environmental and public health concern in Sri Lanka, yet island-wide comparative evidence covering both fine and coarse particulate matter remains limited. This study evaluated spatial and temporal patterns of PM_{2.5} and PM₁₀ using daily observations from twenty National Building Research Organisation monitoring stations from March 2020 to December 2024. Daily rainfall records were available for nine stations and were used to examine the relationship between precipitation and particulate concentrations. Descriptive statistics, annual and seasonal comparisons, Pearson correlation and compliance assessment against World Health Organization guidelines and Sri Lankan national standards were applied. Mean PM_{2.5} concentrations ranged from 15.10 µg/m³ at Nuwara Eliya to 28.28 µg/m³ at Badulla, while mean PM₁₀ concentrations ranged from 21.86 µg/m³ at Nuwara Eliya to 40.11 µg/m³ at Jaffna. All twenty stations exceeded the World Health Organization annual guidelines for both pollutants, although period-average concentrations remained within the Sri Lankan national annual standards. The lowest annual concentrations occurred in 2021, followed by substantial increases from 2022 onwards. Both pollutants were consistently higher during the northeast monsoon period. Rainfall showed only weak negative-to-negligible relationships with particulate concentrations. The results demonstrate substantial spatial and temporal variability and indicate that regional transport and seasonal atmospheric processes are important considerations for particulate pollution management in Sri Lanka.

Keywords: Inter-station comparison, Monsoon seasonality, NBRI, Particulate matter, Transboundary pollution

1. Introduction

Previous studies have largely concentrated on major urban locations such as Colombo and Kandy, limiting understanding of how particulate pollution varies across the wider country. Studies have also identified the influence of regional atmospheric transport, including the movement of dust and combustion-related pollutants from South Asia into Sri Lanka, particularly during the northeast monsoon [1]. The December 2022 Mandous cyclone further demonstrated the potential for transboundary transport to produce severe particulate pollution episodes in Sri Lanka [4]. At the same time, COVID-19 restrictions provided an unusual period in which reductions in traffic and other human activities could be reflected in measured pollutant concentrations [2].

Despite these developments, a gap remains in systematic island-wide comparison of PM_{2.5} and PM₁₀ using the full available multi-station monitoring network. The present study therefore examines particulate pollution across twenty monitoring stations from March 2020 to December 2024. The analysis focuses on spatial differences between stations, changes through time, monsoon-related seasonality, the relationship between rainfall and particulate concentrations at stations with concurrent meteorological observations, and compliance with health-based and national air quality criteria. The study provides a comparative evidence base for interpreting particulate pollution beyond individual urban centres and for identifying locations that warrant closer monitoring and source-specific investigation.

2. Methodology

Daily mean PM_{2.5} and PM₁₀ concentrations were obtained from the National Building Research Organisation monitoring network for twenty stations distributed across Sri Lanka. The study period extended from March 2020 to December 2024. Data quality control included removal of negative particulate concentrations, review of extreme observations, and retention of valid observations for each station. Stations with shorter observation periods were included in spatial comparisons but were interpreted cautiously when assessing multi-year trends. Rainfall data from the Department of Meteorology were available concurrently for Anuradhapura, Badulla, Colombo, Embilipitiya, Galle, Jaffna, Kurunegala, Monaragala and Ratnapura.

For each station, arithmetic mean, median, standard deviation, minimum, maximum and valid observation counts were calculated. Annual mean concentrations were calculated for each available station-year, and inter-annual changes were compared to describe temporal behaviour. Monthly means were used to examine seasonality in relation to the northeast monsoon, first inter-monsoon, southwest monsoon and second inter-monsoon periods. A seasonal contrast ratio was calculated by comparing northeast monsoon and southwest monsoon means. The PM₁₀-to-PM_{2.5} ratio was also examined as an indicative measure of differences in coarse and fine particulate contributions. These comparative measures were used alongside the statistical summaries to interpret spatial, temporal and seasonal patterns rather than relying on statistical significance alone.

Pearson correlation coefficients were calculated between paired daily rainfall and particulate observations at the nine concurrent stations, with statistical significance assessed at the five percent level. Compliance was evaluated against the World Health Organization 2021 annual and twenty-four-hour guidelines and Sri Lankan National Ambient Air Quality Standards. The percentage of monitored days exceeding the World Health Organization twenty-four-hour guidelines was calculated for both pollutants. Data management and tabulation were conducted using Microsoft Excel and Tableau.

3. Results and Discussion

Marked spatial differences were observed across the monitoring network. Mean PM_{2.5} concentrations ranged from 15.10 micrograms per cubic metre at Nuwara Eliya to 28.28 at Badulla, while mean PM₁₀ ranged from 21.86 at Nuwara Eliya to 40.11 at Jaffna. PM₁₀ exceeded PM_{2.5} at every station. The PM₁₀-to-PM_{2.5} ratio ranged from 1.305 to 1.626, with relatively high ratios at Jaffna and Colombo. Jaffna recorded the largest observed PM₁₀ maximum of 264 micrograms per cubic metre, while the largest PM_{2.5} maximum was 139 micrograms per cubic metre.

All twenty stations exceeded the World Health Organization 2021 annual guidelines of 5 micrograms per cubic metre for PM_{2.5} and 15 micrograms per cubic metre for PM₁₀. Annual PM_{2.5} concentrations were approximately three to six times the guideline, while PM₁₀ was approximately 1.5 to 2.7 times higher. Nevertheless, all stations complied with the Sri Lankan national annual standards on a period-average basis. Daily PM_{2.5} exceedance ranged from 44 percent to 99 percent of monitored days, whereas PM₁₀ exceedance ranged from 2 percent to 30 percent.

The lowest annual concentrations occurred in 2021 at all stations with sufficient multi-year records. Concentrations increased sharply in 2022 and remained elevated through 2023 and 2024. At several stations, the increase from 2021 to 2022 was approximately 58 to 67 percent for PM_{2.5} and 37 to 79 percent for PM₁₀. The strong 2022 increase, particularly at Jaffna and Colombo, is consistent with the transboundary pollution episode associated with the Mandous

cyclone [4]. The 2021 reduction is also consistent with documented decreases in urban pollution during COVID-19 restrictions [2].

Both pollutants were consistently higher during the northeast monsoon from December to March and lower during the southwest monsoon. The strongest contrasts occurred at Jaffna, Colombo and Galle. At Jaffna, the northeast-to-southwest seasonal ratios were approximately 1.9 for PM_{2.5} and 1.6 for PM₁₀, while monthly PM₁₀ reached 57.9 micrograms per cubic metre in December. These patterns are consistent with regional atmospheric transport during the northeast monsoon [1].

Rainfall showed only weak relationships with particulate concentrations. Across the nine concurrent stations, Pearson correlations ranged from minus 0.120 to plus 0.007 for PM_{2.5} and from minus 0.101 to plus 0.019 for PM₁₀. The strongest negative associations occurred at Kurunegala, Monaragala and Ratnapura, while relationships at Jaffna and Galle were close to zero. The strong positive relationship between station-level mean PM_{2.5} and PM₁₀, with a Pearson correlation coefficient of 0.93, indicates shared drivers. Overall, particulate pollution should be interpreted using spatial context, seasonal atmospheric circulation and source characteristics rather than rainfall alone.

4. Conclusions

The study demonstrates substantial spatial and temporal variability in particulate pollution across Sri Lanka. All twenty monitoring stations exceeded the World Health Organization annual guideline values for both PM_{2.5} and PM₁₀, despite remaining within the current Sri Lankan national annual standards on a period-average basis. The lowest concentrations were observed at Nuwara Eliya, while Badulla had the highest mean PM_{2.5} and Jaffna had the highest mean PM₁₀ and the most pronounced coarse-particle episodes. The common 2021 minimum, subsequent increase from 2022 onwards, and strong northeast monsoon enhancement indicate that particulate pollution is influenced by both changes in human activity and regional atmospheric processes. The weak rainfall correlations show that precipitation alone is insufficient to explain particulate variability.

The findings support continued strengthening of the national monitoring network, improved integration of meteorological observations, and targeted source investigations at stations with distinctive pollution signatures. Future studies should incorporate wind fields, atmospheric transport analysis, chemical composition and source-apportionment methods to distinguish local emissions from transboundary contributions more directly.

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