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Association Between PM2.5 Concentration and Dengue incidence: A Robust Regression Analysis of Three Regions in India

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ABSTRACT:

Dengue fever primarily spreads through the bite of the female Aedes aegypti mosquito, with symptoms including headaches, muscle and joint pain, rash, and fatigue, which may progress to dengue hemorrhagic fever (DHF) or dengue shock syndrome (DSS). In January 2024, there were over 500,000 dengue cases and 100 deaths globally.

Particulate matter 2.5 (PM2.5) is a significant air pollutant capable of penetrating the lungs and entering the bloodstream. The Indian government's National Clean Air Programme (NCAP) aimed to reduce particulate pollution by 20-30% nationally by 2024. However, separate studies have suggested a negative correlation between PM2.5 levels and humidity and a positive correlation between relative humidity and dengue incidence. This study aimed to analyze the relationship between dengue incidence and PM2.5 concentrations. We hypothesize that increased PM2.5 may be associated with reduced dengue incidence due to its potential effects on humidity and dengue vector breeding conditions.

The relationship between PM2.5 concentrations and dengue incidence in Delhi (2006-2021), Kerala (2006-2021), and Karnataka (2002-2021) was analyzed using robust regression models in RStudio. Statistical significance was set at $p < 0.05$. Analyses demonstrated a significant negative association between PM2.5 and dengue cases in Delhi ($p = 0.0158$) and a significant positive association in Karnataka ($p = 0.0405$). The association in Kerala was not statistically significant ($p = 0.0731$). These findings suggest the relationship between air pollution and dengue incidence is complex and warrants further investigation to inform air quality and vector-borne disease management strategies.

Keywords: Dengue, PM2.5, incidence, Delhi, Kerala, Karnataka.

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INTRODUCTION:

Background: Dengue fever primarily spreads through the bite of the female Aedes aegypti mosquito, with transmission facilitated by the virus to the host[1]. It presents as a sudden onset of high fever, accompanied by severe headache, joint and muscle pain, rash, and fatigue[2]. In severe cases, it can progress to dengue hemorrhagic fever (DHF) or dengue shock syndrome (DSS), marked by bleeding, plasma leakage, and organ failure, which can be fatal without timely medical intervention[2]. Repeated infections with different serotypes increase the risk of severe outcomes[2]. In January 2024, over half a million dengue cases and 100 deaths were reported globally[3]. Diagnosis often relies on clinical presentation and serological tests, while treatment is mainly supportive, focusing on managing dehydration and preventing shock[2]. There are no vaccines against dengue due to its virus's rapid mutation rate[1]. Humidity levels provide ideal conditions for Aedes aegypti mosquito survival and reproduction, enhancing their feeding activity, promoting hatching of eggs and development of larvae in stagnant water sources[4]. These factors collectively increase mosquito populations and the risk of dengue transmission. Conversely, low humidity can reduce mosquito activity and survival rates, limiting their ability to spread dengue. Particulate matter 2.5 (PM2.5) refers to air pollutant particles with a diameter of 2.5 micrometers or less, capable of penetrating into the lungs and entering the bloodstream[4]. It is generated from sources such as industrial activities, combustion of fuels, and natural phenomena like wildfires[4]. India is the world's second-most polluted country[5]. PM2.5 shortens an average Indian's life expectancy by 5.3 years, relative to what it would be if the World Health Organization (WHO) guideline of 5 μg/m^3 was met[5]. In 2019, India launched the National Clean Air Programme (NCAP), aiming to reduce particulate pollution by 20-30% nationally by 2024, focusing on 102 cities failing to meet India's PM2.5 standards[6]. At higher humidity levels, PM2.5 particles absorb moisture, grow heavier, and undergo dry deposition, the process of settling out of the air and depositing on the ground without the aid of precipitation, and consequently reducing PM2.5 concentrations[4]. Separate studies have suggested a negative correlation between PM2.5 levels and humidity[4], and a positive correlation between relative humidity and dengue incidence[1]. Should these associations be confirmed in future studies, they may highlight the importance of considering the interactions between air quality interventions and vector-borne disease incidence. These findings would carry global implications for current policies aimed at lowering PM2.5 exposure to meet WHO standards. Our scientific hypothesis states that an increase in PM2.5 will reduce dengue incidence, as PM2.5 tends to lower humidity levels, which is crucial for dengue vector breeding. Our statistical null hypothesis (H_0) posits that there is no significant relationship between the concentration of PM2.5 and the incidence of dengue. Conversely, the alternative hypothesis (H_A) posits that a statistically significant relationship exists between the concentration of PM2.5 and the incidence of dengue.

METHODS:

Population: The study included data from residents of all ages in three distinct regions in India: Delhi, Kerala, and Karnataka. We chose these three states based on the Air Quality Life Index (AQLI) 2021 dataset[5]. In this dataset, all annual average PM2.5 values (measured in micrograms per cubic meter: μg/m^3) were population weighted[5].

Delhi is identified as the most polluted city in the world, with an annual PM2.5 concentration of 126.5 μg/m^3, far exceeding both the WHO's guideline of 5 μg/m^3 and India's national standard of 40 μg/m^3[5]. The annual average PM2.5 concentration in Kerala is reported as 18.5 μg/m^3, which exceeds the WHO guideline of 5 μg/m^3 but is relatively lower than the national average[5]. The annual average PM2.5 concentration is 29 μg/m^3, also exceeding the WHO guideline but closer to the national standard of 40 μg/m^3[5].

Therefore, Delhi was chosen due to its high, Kerala for low, and Karnataka for low-moderate PM2.5 concentration.

Study Design: The study employed a retrospective secondary data analysis approach. Dengue incidence data collection was conducted through systematic retrieval from peer-reviewed journals and government databases[7,8,9]. PM2.5 concentration data in Delhi from 2006 to 2021 was obtained from the Transportation Research and Injury Prevention (TRIP) Centre, affiliated with the Indian Institute of Technology[10]. Data for Kerala from 2006 to 2021, and for Karnataka from 2002 to 2021, was collected from the Air Quality Life Index[5]. The final analyzed datasets consisted of 16 annual observations of dengue cases and PM2.5 concentrations for Delhi and Kerala, and 20 annual observations for Karnataka.

Statistical Analysis: The relationship between dengue case incidence and PM2.5 levels was analyzed using robust regression to account for the influence of outliers. Outliers were identified via boxplots created using the (boxplot) function in R and retained in the dataset, as they were determined to represent actual variability rather than random noise. To address potential temporal lags in the data, dengue case counts were shifted by one year. This adjustment was based on the observation that air pollution levels typically peak at the end of the year, potentially influencing subsequent dengue incidence[11]. The increase in air pollution towards the end of the year can be attributed to a festival celebrated in India with firecrackers called Diwali. Missing values for dengue cases in Karnataka from 2009 to 2012 were addressed using robust regression with the MM-estimator, implemented via the (lmrob) function from the (robustbase) package. Robust regression models were fitted separately for three datasets to minimize the influence of missing or extreme data points while ensuring robust parameter estimation. Normality was checked using shapiro wilk test and it was identified that the datasets were not normally distributed.

Key assumptions of the robust regression models, including linearity and homoscedasticity, were validated through diagnostic plots. Scatterplots of observed versus fitted values (plot(fitted(model), observed)) and residual plots (plot(residuals(model))) were generated to confirm that these assumptions were met. Any deviations were examined, but no transformations were ultimately required. The robust regression analyses were conducted at a significance level of 0.05, with 95% confidence intervals for all coefficients. Model summaries, including p-values and confidence intervals, were interpreted using the (summary()) function in R. All statistical analyses were conducted in RStudio, utilizing (robustbase) for robust regression and base R functions for visualization and diagnostics.

RESULTS:

For Delhi, p(x) was 0.01583, p(y) was 0.00298, and the adjusted variance was 9.92%, signifying a significant negative relationship between PM2.5 and dengue. For Karnataka, p(x) was 0.0405, p(y) was 0.0493, and adjusted variance was 14.95%, signifying a significant positive relationship between PM2.5 and dengue. For Kerala, p(x) was 0.0731, p(y) was 0.2375, and adjusted variance is 3.35%, signifying a marginally significant positive relationship between PM2.5 and dengue.

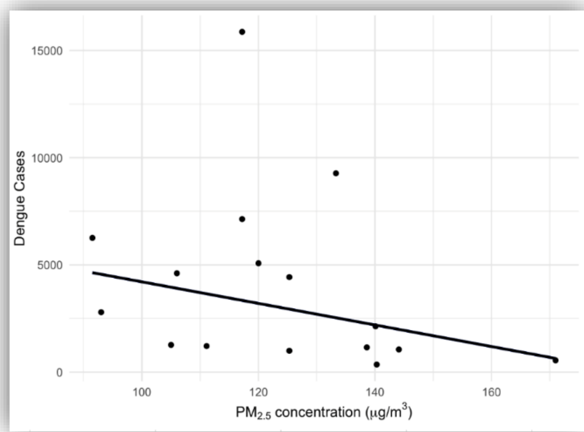

FIG-1. The robust regression analysis reveals a significant negative relationship between PM2.5 concentration ("x") and Dengue Cases ("y") in Delhi.

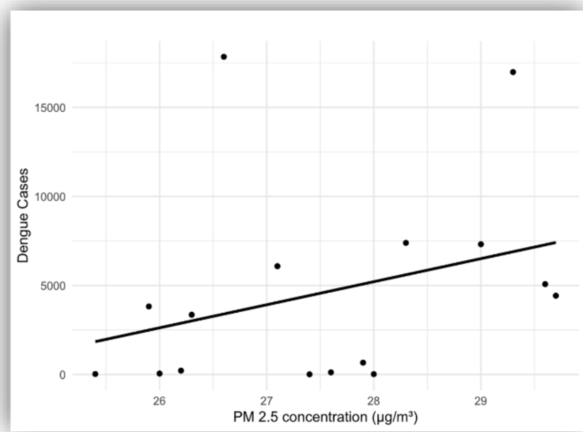

FIG-2. The robust regression analysis reveals a significant positive relationship between PM2.5 concentration ("x") and Dengue Cases ("y") in Karnataka.

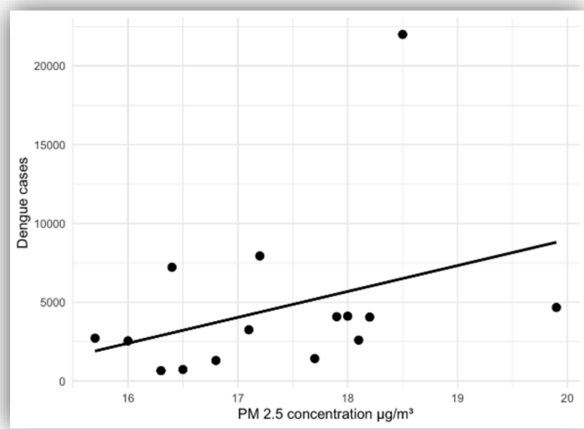

FIG-3. The robust regression analysis reveals a marginally significant positive relationship between PM2.5 concentration ("x") and Dengue Cases ("y") in Kerala.

DISCUSSION: A previously conducted study suggests a negative correlation between PM2.5 and humidity above a certain threshold[4], and another suggests an inverted-U relationship between PM2.5 and humidity[12]. At the beginning, as the x variable increases, there is a corresponding increase in the y variable. This happens until a certain threshold; however, past this threshold, as x increases, the relationship between the variables changes from positive to negative and y starts to decrease. In the context of this study, PM2.5 is the x variable and humidity is the y variable. As PM2.5 increases from low to moderate, it has a positive relationship with humidity and thus an increase in PM2.5 results in an increased relative humidity. Once PM2.5 reaches moderate levels and continues to increase, the graph reaches its peak and changes direction. Therefore, an increase in PM2.5 from moderate to high amounts actually results in a decrease in relative humidity.

A significant trend was detected: when PM2.5 levels are generally low in an area, there is a positive relationship between PM2.5 levels and dengue cases. This means that as PM2.5 levels increase, dengue cases also increase. This trend was observed in two places: Karnataka and Kerala, where PM2.5 levels were in the range of 25.4 to 29 and 15.7 to 19.9, respectively, which is relatively low, yet there was an increase in dengue cases. Additionally, it is worth noting that in Kerala, the relationship between PM2.5 levels and dengue cases was marginally significant, with an adjusted R-squared value of 3.35%, suggesting potential confounding factors. On the other hand, in areas where PM2.5 levels were generally higher, in the range of the 100s, an increase in PM2.5 levels led to a decrease in dengue cases. For example, in Delhi, where PM2.5 levels ranged from 91.5 to 171, there was a decrease in dengue cases as PM2.5 levels increased. This can be seen because the relatively lower PM2.5 levels have increased the overall humidity in the area, whereas the higher PM2.5 levels have decreased the overall humidity. This may contribute to differences in dengue incidence observed between areas with varying PM2.5 concentrations

In the context of Delhi, data from 2006 to 2021 indicates a consistent decrease in temperature[13], suggesting a less favourable environment for mosquito proliferation[14]. Moreover, the decline in rainfall, as evidenced by decreased precipitation patterns[15], further limits the availability of stagnant water essential for mosquito breeding[14]. Increased urbanization density in Delhi[16], leading to substantial development in sewage systems potentially reducing mosquito breeding grounds and thus dengue transmission rates. These factors collectively contribute to the observed negative association between dengue incidence and PM2.5 levels in Delhi. Despite relatively consistent temperatures in Karnataka[17], the region has experienced an increase in annual average rainfall, particularly notable from 2016 to 2020[18]. Increased precipitation provides conducive conditions for mosquito breeding, potentially leading to higher dengue transmission rates[14]. Additionally, Karnataka has a lower urban density than Delhi[19], implying a less developed sewage system, potentially exacerbating mosquito breeding grounds and dengue transmission.

Confounding variables, including temperature fluctuations, rainfall patterns, levels of urbanization, and local vector control measures, limit the study's findings. Delhi, Karnataka, and Kerala exhibit diverse socioeconomic statuses and environmental characteristics, such as humidity levels and green landscapes, which may influence the relationship between PM2.5 pollution and dengue differently across these areas. Focusing solely on these states may only partially capture the range of factors affecting the correlation between PM2.5 pollution and dengue incidence. Moreover, access to data for Karnataka's dengue cases from 2009 to 2012 was unavailable, potentially limiting the comprehensiveness of the analysis for this period. Limited budget constraints prevented access to more extensive datasets requiring paid access. Finally, because this study used retrospective observational data, causal relationships cannot be established. The observed associations may reflect interactions between multiple environmental, demographic, and socioeconomic factors.

CONCLUSION: This study analyzed the relationship between PM2.5 concentrations and dengue incidence across three Indian states: Delhi, Kerala, and Karnataka, representing varying levels of air pollution. The results suggest that PM2.5 concentrations may be associated with dengue incidence differently across regions with varying environmental conditions. Specifically, regions with higher PM2.5 levels, like Delhi, demonstrated a negative correlation between PM2.5 and dengue cases, while regions with lower PM2.5 levels relative to Delhi, such as Kerala and Karnataka, exhibited a positive correlation, which may support the hypothesis that particulate matter could influence factors affecting mosquito breeding. These findings highlight the need for a nuanced approach to air pollution mitigation strategies, integrating considerations of vector-borne disease dynamics into policy frameworks.

However, further studies incorporating additional environmental and socioeconomic variables are needed before implications for air quality policies can be determined.

Despite the robust statistical methods employed, this study is limited by potential confounding factors, including temperature variations, rainfall patterns, urbanization levels, and local vector control measures. Future research should incorporate broader geographic regions and more detailed environmental data to better understand the multifaceted relationship between air pollution and dengue incidence. Addressing these limitations will provide a clearer framework for balancing air quality improvement with public health interventions targeting vector-borne diseases.

LIST OF ABBREVIATIONS:

PM2.5 - Particulate matter of diameter 2.5µm, **WHO** - World Health Organization, **AQLI**- Air Quality Life Index, **TRIP** - Transportation Research and Injury Prevention, **NCAP** - National Clean Air Programme.

CONFLICT OF INTEREST: The authors declare that they have no conflicts of interest.

ETHICS APPROVAL: Our study did not require ethics approval or participant consent, as we did not access any personal records. All data used in this study was publicly available; therefore, no consent was required. The study involved no physical testing or direct interaction with participants, as all data was retrospective and non-identifiable.

AUTHORS' CONTRIBUTIONS: AJ: Involved in data collection, analysis, interpretation, drafting manuscript, revising work critically for important intellectual content, and final approval of the version to be published. **AMH**: Made contributions to the literature review and study design, as well as the collection, analysis, and interpretation of data. Drafted manuscript, revised work critically for important intellectual content, and gave final approval for the version to be published. **KS**: Involved in data collection, analysis, interpretation, drafting manuscript, and revising work critically for important intellectual content.

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