**Methods:**

We analyzed the national-level average case fatality rate (CFR) for dengue from 2020 to 2024 as the outcome variable. Predictor variables included the national annual average concentration of PM2.5, total annual rainfall 1, average annual temperature 1, percentage of the urban population in 2023 2, population density in 2022 (people per square kilometer of land area) 3, prevalence of diabetes among individuals aged 20–79 in 2021 4, prevalence of hypertension among individuals aged 30–79 in 2023 5, and gross domestic product (GDP) per capita in 2023 (current US$)6.

To identify independent predictors of dengue cases and deaths, we employed a generalized linear mixed model (GLMM) with a Poisson distribution, suitable for analyzing time series data. The GLMM extends the generalized linear model by accounting for clustered categorical data, such as repeated measures across subjects 8. A key advantage of this approach is its ability to model hierarchical structures, effectively partitioning variability at different levels, this study, accounting for clustering by both country or territory and year. While location and year were treated as time-invariant grouping factors, the independent variables were considered temporally consistent at the national level within each respective year. All statistical analyses were performed using R software (version 3.5.2.2) 9.

**Results:** In the GLMM analysis, countries with higher PM2.5 levels exhibited a significantly greater risk of fatal outcomes (Incidence Rate Ratio [IRR]: 1.94, 95% CI: 1.60–2.37), suggesting that each percentage increase in PM2.5 is associated with a 94% increase in dengue fatality risk compared to countries with lower PM2.5 levels. On the other hand, countries with higher GDPs experienced a lower risk of fatal outcomes (IRR: 0.65, 95% CI: 0.55–0.78), indicating a 35% reduction in dengue fatality rates in wealthier countries for an increase of GDP by one unit ($1).

Table 1: Factors associated with the Case fatality rate (CFR) of Dengue in endemic countries using Generalized linear mixed model

|  |  |  |  |
| --- | --- | --- | --- |
| **Variables** | **IRR** | **95% CI** | **P-value** |
| PM2.5 | 1.36 | 1.09 - 1.70 | 0.007 |
| Total Rainfall | 1.05 | 0.86 - 1.28 | 0.627 |
| Average Temperature | 1.01 | 0.82 - 1.25 | 0.902 |
| Urban Population (%) | 1.23 | 0.90 - 1.70 | 0.199 |
| Population Density | 2.30 | 1.26 – 4.20 | 0.007 |
| Diabetes (%) | 0.83 | 0.65 - 1.06 | 0.136 |
| Hypertension (%) | 1.51 | 1.12 – 2.03 | 0.006 |
| GDP Per capita ($) | 0.38 | 0.21 - 0.70 | 0.002 |
|  |  |  |  |
| **AIC** | 257.34 | **RMSE** | 0.73 |
| **BIC** | 288.61 | **R2 (%)** | 32.60 |

*Note. RR = relative risk; CI = confidence interval.*

*\*p < 0.1. \*\*p < .05. \*\*\*p < .01.*



**References:**

1 NASA. NASA POWER | DAV. 2025. https://power.larc.nasa.gov/data-access-viewer/ (accessed July 2, 2025).

2 OWID. Urbanization. https://ourworldindata.org/urbanization (accessed July 2, 2025).

3 World Bank. World Development Indicators. 2025. https://databank.worldbank.org/source/world-development-indicators/Series/EN.POP.DNST (accessed July 2, 2025).

4 OWID. Diabetes prevalence. 2025. https://ourworldindata.org/grapher/diabetes-prevalence (accessed July 2, 2025).

5 WHO. Global report on hypertension: the race against a silent killer. *https://www.who.int/publications/i/item/9789240081062* 2023; : 1–291.

6 World Bank. GDP per capita (current US$). 2025. https://data.worldbank.org/indicator/NY.GDP.PCAP.CD (accessed July 16, 2025).

7 Haider N, Hasan MN, Guitian J, *et al.* The disproportionate case–fatality ratio of COVID-19 between countries with the highest vaccination rates and the rest of the world. *IJID Regions* 2023; **6**: 159–66.

8 The R Core Team. R: A Language and Environment for Statistical Computing. https://www.gnu.org/copyleft/gpl.html. (accessed July 2, 2025).

**Suppl. Table 7.**  Correlation matrix between key variables (Pearson r)

| **Variable** | **PM₂.₅** | **CFR (%)** | Total Rainfall | Average Temperature | Urban Population | Population Density | GDP per Capita (USD) |
| --- | --- | --- | --- | --- | --- | --- | --- |
| PM₂.₅ | 1.00 | **0.57** | -0.15 | 0.25 | -0.55 | -0.11 | -0.32 |
| Dengue CFR (%) | 0.57 | 1.00 | -0.07 | 0.19 | -0.33 | -0.08 | -0.23 |
| Total Rainfall | -0.15 | -0.07 | 1.00 | 0.42 | 0.34 | 0.38 | 0.47 |
| Average Temperature | 0.25 | 0.19 | 0.42 | 1.00 | -0.14 | 0.28 | 0.15 |
| Urban Population | -0.55 | -0.33 | 0.34 | -0.14 | 1.00 | 0.29 | 0.59 |
| Population Density | -0.11 | -0.08 | 0.38 | 0.28 | 0.29 | 1.00 | 0.88 |
| GDP per Capita (USD) | -0.32 | -0.23 | 0.47 | 0.15 | 0.59 | 0.88 | 1.00 |