GBMN GEORGIAN BIOMEDICAL & MEDICAL NEXUS
Former Georgian Biomedical News
VOLUME 4 ISSUE 3. JUL-SEP 2026

Long-Term $PM_{2.5}$ Exposure and Attributable Mortality in Tbilisi, Georgia: A Health Impact Assessment Using AirQ+

Tamari Kashibadze[1,ID], Ekaterine Ruadze[2,ID], Nino Kiladze[1,ID]

ABSTRACT

BACKGROUND. Long-term exposure to fine particulate matter ($PM_{2.5}$) is a major environmental risk factor for premature mortality. However, evidence quantifying the health burden attributable to $PM_{2.5}$ exposure in Georgia remains limited.

OBJECTIVES. To estimate the impact of long-term $PM_{2.5}$ exposure on natural all-cause mortality in Tbilisi and evaluate potential health benefits under hypothetical pollution-reduction scenarios.

METHODS. We conducted a health impact assessment using the WHO AirQ+ software and multi-year air-quality and mortality data for Tbilisi during 2019-2024. Annual $PM_{2.5}$ concentrations from fixed monitoring stations were used to calculate a six-year mean concentration of 17.3 μg/m³. The analysis focused on natural all-cause mortality among adults aged ≥30 years using concentration-response functions recommended for AirQ+. Attributable mortality was estimated for current exposure levels and for hypothetical $PM_{2.5}$ reduction scenarios, including reductions of 5 μg/m³, 10 μg/m³, and attainment of the WHO annual air quality guideline value of 5 μg/m³.

RESULTS. Long-term $PM_{2.5}$ exposure was estimated to account for 9.0% (95% CI: 6.9%-10.1%) of natural all-cause deaths among adults aged ≥30 years in Tbilisi, corresponding to approximately 1,081 premature deaths annually (95% CI: 828-1,204). Reducing $PM_{2.5}$ concentrations by 5 μg/m³ and 10 μg/m³ was associated with decreases in attributable mortality to 654 and 210 premature deaths annually, respectively. Under the WHO guideline scenario, no additional $PM_{2.5}$-attributable mortality was estimated within the model framework.

CONCLUSIONS. $PM_{2.5}$ exposure represents a substantial public health burden in Tbilisi. The findings indicate that reductions in ambient $PM_{2.5}$ concentrations could prevent a considerable number of premature deaths and support the need for strengthened air-quality management and progressive alignment with WHO guideline values.

KEYWORDS. Air pollution; AirQ+; Health impact assessment; Mortality; $PM_{2.5}$

DOI. 10.52340/GBMN.2026.01.01.187

BACKGROUND

Exposure to air pollution is recognized as a major determinant of population health and is associated with numerous acute and chronic diseases, contributing to millions of premature deaths each year.[1,2] According to the World Health Organization (WHO), approximately 99% of the global population breathes air that exceeds WHO air quality guideline levels, with the highest exposures occurring in low- and middle-income countries.[3]

Among ambient air pollutants, fine particulate matter with an aerodynamic diameter ≤2.5 μm ($PM_{2.5}$) is considered one of the most harmful to human health. A substantial body of epidemiological evidence has demonstrated that long-term exposure to $PM_{2.5}$ increases the risk of all-cause mortality and major noncommunicable diseases, including ischemic heart disease, stroke, chronic respiratory disease, and lung cancer.[4-6] Due to their small size, fine particles can penetrate deep into the pulmonary alveoli and enter the bloodstream, contributing to systemic inflammation and adverse cardiovascular and respiratory outcomes.[7] The Global Burden of Disease Study 2019 estimated that $PM_{2.5}$ exposure accounted for more than 4.1 million deaths and 118.2 million disability-adjusted life years (DALYs) worldwide.[8]

Rapid urbanization in many low- and middle-income countries has contributed to persistent deterioration in urban air quality.[9] Georgia, particularly its capital city Tbilisi, reflects this trend, with dense population, increasing motorization, construction activity, and other emission sources contributing to $PM_{2.5}$ concentrations that frequently exceed WHO guideline values.[10]

Despite growing recognition of air pollution as a public health concern in Georgia, evidence on the long-term health impacts of $PM_{2.5}$ exposure remains limited. Previous studies in Tbilisi have primarily focused on temporal and spatial trends in particulate matter concentrations and on identifying major emission sources, especially traffic and industrial

GBMN GEORGIAN BIOMEDICAL & MEDICAL NEXUS
Former Georgian Biomedical News
VOLUME 4 ISSUE 3. JUL-SEP 2026

activities.[10-12] However, there is limited evidence quantifying the mortality burden attributable to long-term $PM_{2.5}$ exposure at the city level.

Therefore, this study aimed to assess the long-term health impact of $PM_{2.5}$ exposure on all-cause mortality among adults in Tbilisi during 2019-2024. Using the WHO AirQ+ software, developed by the WHO Regional Office for Europe, we estimated mortality attributable to long-term $PM_{2.5}$ exposure and modeled hypothetical reduction scenarios relative to WHO air quality guideline levels and intermediate reductions in annual mean $PM_{2.5}$ concentrations.[13-15]

METHODS

Study area

This study was conducted in Tbilisi, the capital and largest city of Georgia, located in the eastern part of the country. Tbilisi accounts for more than one-third of the national population and is characterized by high traffic density, rapid urbanization, and localized industrial activity. Air pollution, particularly particulate matter ($PM_{2.5}$), represents a major environmental health concern in the city. Recent World Bank analyses reported average monthly $PM_{2.5}$ concentrations of approximately 20 $\mu g/m^3$, nearly four times higher than the WHO annual air quality guideline value. [12]

Tbilisi was selected as the study area because it has the most extensive ambient air-quality monitoring network in Georgia and relatively comprehensive data on $PM_{2.5}$ concentrations, population characteristics, and mortality indicators.

Study period

This retrospective study covered the period from 1 January 2019 to 31 December 2024. The study period was selected to reflect recent exposure conditions in Tbilisi and to utilize continuously available air-quality and mortality data. Annual mean $PM_{2.5}$ concentrations were calculated from daily monitoring data and linked with annual population and mortality statistics for the health impact assessment.

$PM_{2.5}$ data

Air-quality data were obtained from the National Environmental Agency (NEA) of Georgia through an official request and from its official air quality portal (https://air.gov.ge/en/), which provides real-time data from automatic stations across the country. During the study period, the air-quality monitoring network in Tbilisi expanded to five automatic monitoring stations. Three stations (Tsereteli Avenue, Kazbegi Avenue and Varketili) are classified as traffic monitoring stations, while the remaining two are urban background stations. However, one urban background station became operational only in 2024, and the other did not have complete data for the entire study period. Therefore, only the three traffic monitoring stations met the inclusion criterion of complete $PM_{2.5}$ data for 2019-2024 and were included in the analysis. No missing values were imputed. The annual mean $PM_{2.5}$ concentration for Tbilisi was calculated as the arithmetic mean of the annual concentrations measured at the three included stations using validated monitoring data, in accordance with the methodology recommended for the WHO AirQ+ software.

Population and mortality data

Population and mortality data for Tbilisi were obtained from the National Statistics Office of Georgia (Geostat). Population estimates for adults aged ≥30 years were derived by applying the age distribution from the 2014 General Population Census to annual population estimates for the period 2019-2024.

Mortality data were classified according to the International Classification of Diseases, 10th Revision (ICD-10). Natural all-cause mortality was defined as deaths with underlying causes coded A00-R99, excluding external causes (V01-Y89), in accordance with WHO recommendations for the application of the AirQ+ software. Consistent with the standard WHO AirQ+ methodology for long-term $PM_{2.5}$ health impact assessment, the analysis was conducted for adults aged ≥30 years.

Statistical analysis and AirQ+

Long-term health impacts of $PM_{2.5}$ exposure were assessed using the AirQ+ software developed by the WHO Regional Office for Europe. AirQ+ is a standardized tool designed to estimate the health burden attributable to ambient air pollution by integrating exposure data, population characteristics,

ISSN (Online): 2720-8796 ISSN (Print): 2720-7994

GBMN GEORGIAN BIOMEDICAL & MEDICAL NEXUS
Former Georgian Biomedical News
VOLUME 4 ISSUE 3. JUL-SEP 2026

baseline mortality rates, and concentration-response functions derived from epidemiological studies. [13]

In this study, AirQ+ (version 2.2.4) was used to estimate natural all-cause mortality attributable to long-term $PM_{2.5}$ exposure among adults aged ≥30 years in Tbilisi during 2019-2024. The primary analysis used a counterfactual concentration (X0) of 5 μg/m³. Model inputs included a single six-year average $PM_{2.5}$ concentration calculated from monitoring data collected during the study period, population estimates for adults aged ≥30 years, and corresponding mortality data for the same population group. The concentration-response relationship between $PM_{2.5}$ exposure and mortality was specified using the default WHO AirQ+ relative risk estimate (RR=1.08; 95% CI: 1.06-1.09), based on published epidemiological evidence. [16]

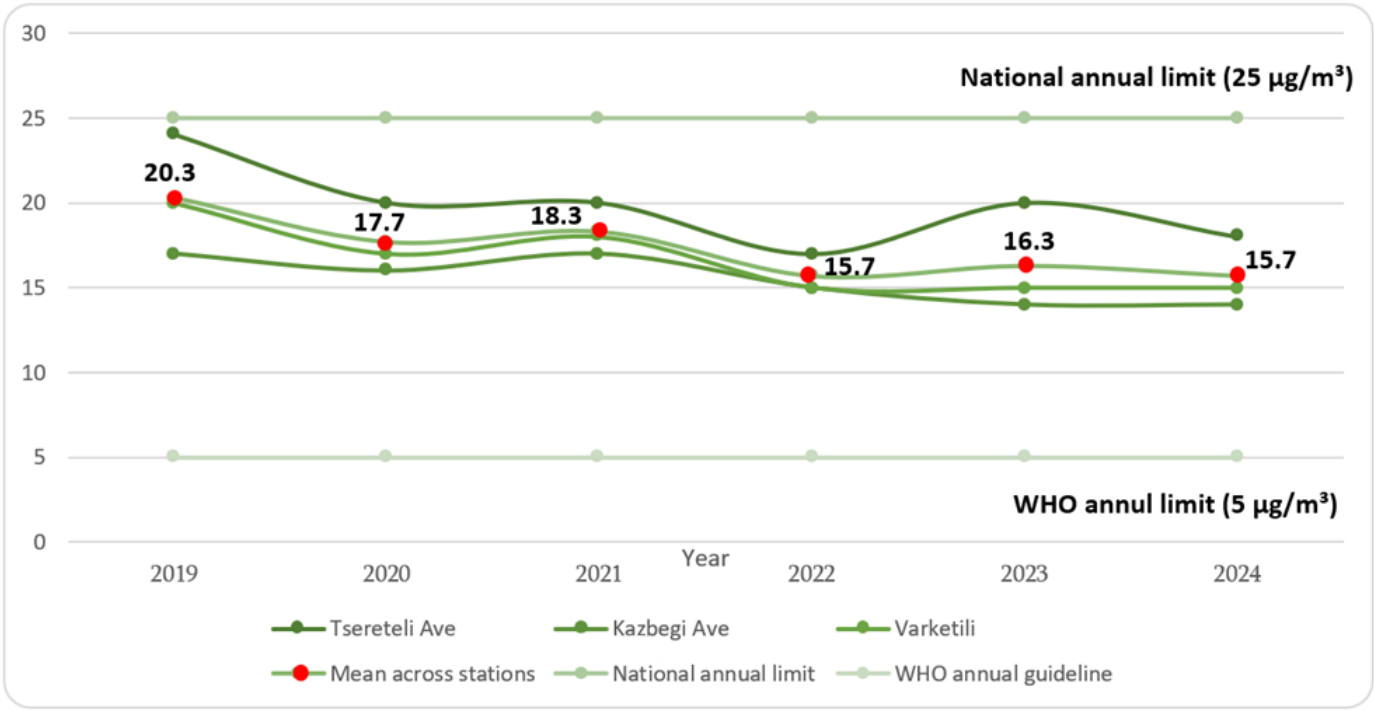
The primary outcomes were the attributable proportion of deaths and the estimated number of premature deaths associated with $PM_{2.5}$ exposure above the selected reference concentration. In addition, hypothetical reduction scenarios were modeled to evaluate potential health benefits associated with achieving the WHO annual $PM_{2.5}$ guideline value and with reductions of 5 μg/m³ and 10 μg/m³ from the observed concentration.

RESULTS

Descriptive statistics

Annual mean $PM_{2.5}$ concentrations measured at monitoring stations in Tbilisi during 2019-2024 are presented in **FIGURE 1**. Across the study period, the highest concentrations were consistently observed at the Tsereteli Avenue station, where annual mean $PM_{2.5}$ levels ranged from 17 to 24 μg/m³ and peaked in 2019. Lower concentrations were recorded at the Kazbegi Avenue and Varketili stations, with annual means generally ranging between 14 and 20 μg/m³.

FIGURE 1. Annual $PM_{2.5}$ Concentrations at monitoring stations and city-wide averages in Tbilisi, 2019-2024



Note: $PM_{2.5}$ concentrations are expressed in μg/m³.

The annual citywide mean $PM_{2.5}$ concentration across the three monitoring stations ranged from 15.7 μg/m³ to 20.3 μg/m³ during the study period. The highest annual mean concentration was observed in 2019 (20.3 μg/m³), while the lowest values were recorded in 2022 and 2024 (15.7 μg/m³). Although annual $PM_{2.5}$ concentrations remained below the national annual limit value of 25 μg/m³ throughout

GBMN GEORGIAN BIOMEDICAL & MEDICAL NEXUS
Former Georgian Biomedical News
VOLUME 4 ISSUE 3. JUL-SEP 2026

the study period, they consistently exceeded the WHO annual air quality guideline value of 5 μg/m³.

Population estimates for Tbilisi were available for each year from 2019 to 2024, while detailed age- and sex-specific distributions were obtained from the 2014 General Population Census. Age- and sex-specific proportions from the census were applied to annual population estimates to derive the number of adults aged ≥30 years by sex for each study year.

According to the 2014 census, adults aged ≥30 years accounted for 57.8% of the total population of Tbilisi, and women represented a larger share of this age group than men. Application of these census-based proportions yielded an estimated population aged ≥30 years ranging from 676,639 in 2019 to 727,137 in 2024, with women consistently comprising the majority of this population group (**TAB.1**). These estimates were used as denominators for calculating natural all-cause mortality rates and as population inputs for the AirQ+ health impact assessment.

TABLE 1. Estimated population of Tbilisi aged ≥30 years by sex, 2019-2024 (based on 2014 census proportions)

Year	Total population	≥30 years total	≥30 years men	≥30 years women
2019	1,171,100	676,639	284,835	391,804
2020	1,184,800	684,555	288,167	396,388
2021	1,202,700	694,897	292,521	402,376
2022	1,201,800	694,377	292,302	402,075
2023	1,241,700	717,431	302,007	415,424

Total mortality among residents of Tbilisi during 2019-2024 is presented in **TABLE 2**. During the study period, 83,193 deaths from all causes were recorded, with slightly more deaths occurring among women (50.7%) than men (49.25%). The highest annual number of deaths was observed in 2021 (17,922 deaths), while lower mortality counts were recorded in 2023 and 2024. When restricted to natural all-cause mortality among adults aged ≥30 years, the annual number of deaths ranged from 11,267 to 12,998, with a total of 71,816 deaths recorded during the study period.

TABLE 2. Deaths among residents of Tbilisi by year and sex, and natural all-cause deaths in adults aged ≥30 years (2019-2024)

Year	Total deaths (all causes, all ages)	Women n (%)	Men n (%)	Natural all-cause deaths (A00–R99, ≥30 years)
2019	12,549	6,369 (50.75)	6,180 (49.25)	11,533
2020	13,878	6,987 (50.35)	6,891 (49.65)	12,053
2021	17,922	9,332 (52.07)	8,590 (47.93)	12,998
2022	14,123	7,100 (50.27)	7,023 (49.73)	12,371
2023	12,229	6,133 (50.15)	6,096 (49.85)	11,267
2024	12,492	6,241 (49.96)	6,251 (50.04)	11,594
2019 -2024 Total	83,193	42,162	41,031	71,816

Data preparation for AirQ+ analysis

In accordance with the AirQ+ methodology, the health outcome was defined as natural all-cause mortality (ICD-10 codes A00-R99), excluding deaths due to external causes such as injuries and traffic accidents. The population at risk was restricted to adults aged ≥30 years, while long-term exposure to air pollution was represented using multi-year mean $PM_{2.5}$ concentrations.

Annual mean $PM_{2.5}$ concentrations for Tbilisi were calculated for each year from 2019 to 2024 using data from fixed monitoring stations. Across the study period, annual mean $PM_{2.5}$ concentrations ranged from 15.7 μg/m³ to 20.3 μg/m³, with a six-year average concentration of 17.3 μg/m³ (**TAB.3**).

Crude mortality rates for natural all-cause mortality among adults aged ≥30 years were calculated per 100,000 population using the following formula:

Georgian Biomedical and Medical Nexus (Former Georgian Biomedical News)
ISSN (Online): 2720-8796 ISSN (Print): 2720-7994

GBMN GEORGIAN BIOMEDICAL & MEDICAL NEXUS
Former Georgian Biomedical News
VOLUME 4 ISSUE 3. JUL-SEP 2026

Crude death rate = (number of deaths/population) × 100,000

To minimize the influence of year-to-year fluctuations related to factors such as epidemics and changes in health-service utilization, multi-year average values were calculated in accordance with AirQ+ guidance. The final AirQ+ inputs therefore consisted of multi-year mean crude mortality rates and multi-year mean $PM_{2.5}$ concentrations for adults aged ≥30 years in Tbilisi.

Over the 2019-2024 period, the mean crude natural all-cause mortality rate among adults aged ≥30 years was 1,712 deaths per 100,000 population, while the corresponding mean $PM_{2.5}$ concentration was 17.3 μg/m³ (**TAB.3**).

TABLE 3. Annual mean $PM_{2.5}$ concentrations and natural all-cause crude mortality rate in adults aged ≥30 years in Tbilisi, 2019-2024

Year	Total population	Population ≥30	Natural all-cause deaths ≥30 (A00-R99)	Crude mortality rate ≥30 (per 100,000)	$PM_{2.5}$ annual mean (μg/m³)
2019	1,171,100	676,639	11,533	1,704.45	20.3
2020	1,184,800	684,555	12,053	1,760.71	17.7
2021	1,202,700	694,897	12,998	1,870.49	18.3
2022	1,201,800	694,377	12,371	1,781.60	15.7
2023	1,241,700	717,431	11,267	1,570.46	16.3
2024	1,258,500	727,137	11,594	1,594.47	15.7
Mean 2019 - 2024	1,210,100	699,173	11,969	1,712	17.3

Health impact of long-term $PM_{2.5}$ exposure

Using the AirQ+ model, we estimated the impact of long-term $PM_{2.5}$ exposure on natural all-cause mortality among adults aged ≥30 years in Tbilisi during 2019-2024. The analysis was based on the six-year mean $PM_{2.5}$ concentration of 17.3 μg/m³ and the corresponding multi-year average natural all-cause mortality rate for this population group. In the primary analysis, the counterfactual concentration was set to the theoretical minimum risk exposure level recommended in the AirQ+ methodology.

The model estimated that 9.0% (95% CI: 6.9%-10.1%) of natural all-cause deaths among adults aged ≥30 years were attributable to long-term $PM_{2.5}$ exposure. This corresponded to an estimated 1,081 premature deaths annually (95% CI: 828-1,204), equivalent to an attributable mortality rate of 154.6 deaths per 100,000 population aged ≥30 years (95% CI: 118.4-172.2). These findings indicate a substantial contribution of $PM_{2.5}$ exposure to premature mortality in the adult population of Tbilisi (**TAB.4**).

TABLE 4. Hypothetical reduction scenarios for long-term $PM_{2.5}$ and attributable natural all-cause mortality in adults aged ≥30 years, Tbilisi

Scenario	$PM_{2.5}$ concentration (μg/m³)	Attributable proportion % (95% CI)	Attributable deaths per year, n (95% CI)	Attributable deaths per 100,000 (95% CI)
Current level	17.3	9.0 (6.9-10.1)	1,081 (828-1,204)	154.6 (118.4-172.2)
- 5 μg/m³	12.3	5.5 (4.2-6.1)	654 (498-730)	93.5 (71.3-104.4)
- 10 μg/m³	7.3	1.8 (1.3-2.0)	210 (159-235)	30.0 (22.8-33.6)
WHO guideline	5.0	0.0	0	0

Hypothetical reduction scenarios for $PM_{2.5}$

Additional analyses were conducted to evaluate the potential health benefits of reducing long-term $PM_{2.5}$ concentrations in Tbilisi. Hypothetical scenarios included reductions of 5 μg/m³ and 10 μg/m³ from the observed six-year mean concentration, as well as a scenario in which $PM_{2.5}$ concentrations were reduced to the WHO annual air quality guideline value of 5 μg/m³.

Under the 5 μg/m³ reduction scenario (12.3 μg/m³), the attributable proportion of natural all-cause mortality decreased to 5.5% (95% CI: 4.2%-6.1%), corresponding to 654 premature deaths annually (95% CI: 498-730) and an attributable mortality rate of 93.5 deaths per 100,000 population (95% CI: 71.3-104.4). A 10 μg/m³ reduction scenario (7.3 μg/m³) further reduced the attributable proportion to 1.8% (95% CI: 1.3%-2.0%), equivalent to 210 premature deaths annually (95% CI: 159-235) and

Georgian Biomedical and Medical Nexus (Former Georgian Biomedical News)
ISSN (Online): 2720-8796 ISSN (Print): 2720-7994

GBMN GEORGIAN BIOMEDICAL & MEDICAL NEXUS
Former Georgian Biomedical News
VOLUME 4 ISSUE 3. JUL-SEP 2026

an attributable mortality rate of 30.0 deaths per 100,000 population (95% CI: 22.8-33.6).

In the scenario where $PM_{2.5}$ concentrations were reduced to the WHO guideline value of 5 µg/m³, the model estimated no additional $PM_{2.5}$-attributable mortality (**TAB.4**).

DISCUSSION

This study quantified the impact of long-term exposure to $PM_{2.5}$ on natural all-cause mortality among adults aged ≥30 years in Tbilisi using the WHO AirQ+ framework and multi-year mortality and air quality data for 2019–2024. At a six-year mean $PM_{2.5}$ concentration of 17.3 µg/m³, an estimated 9.0% of natural all-cause deaths in this age group were attributable to $PM_{2.5}$, corresponding to about 1,081 premature deaths per year and 154.6 deaths per 100,000 population aged ≥30 years. These findings indicate a substantial mortality burden associated with ambient $PM_{2.5}$ exposure in Tbilisi.

Several recent studies using the AirQ+ tool provide useful comparisons for interpreting these findings. A national AirQ+ assessment in Serbia estimated approximately 3,585 premature deaths annually attributable to long-term $PM_{2.5}$ exposure across 11 major cities, including around 1,796 deaths in Belgrade. [17] Similarly, a study conducted in Mashhad during 2016-2021 reported annual $PM_{2.5}$ concentrations ranging from 24 to 33 µg/m³ and estimated approximately 1,800-2,400 attributable deaths annually, with attributable fractions between 10% and 15% depending on the year and baseline incidence. [18] Although differences in population size, exposure levels, and methodological assumptions limit direct comparison, the estimated burden observed in Tbilisi is consistent with findings from other urban settings with elevated $PM_{2.5}$ exposure.

A major strength of this study is the use of multi-year exposure and mortality averages, which reduces the influence of short-term fluctuations and unusual events, including the marked increase in mortality observed during the COVID-19 pandemic in 2021. The use of the standardized WHO AirQ+ framework also improves comparability with international studies and provides a transparent approach for health impact assessment.

Several limitations should also be considered. First, population estimates for adults aged ≥30 years were derived using age- and sex-specific proportions from the 2014 census, which may not fully reflect demographic changes during the 2019–2024 study period, including population aging, migration, and urban population growth, As these estimates were used to derive the population denominator for the health impact assessment, any discrepancies may have influenced the estimated mortality burden. Second, exposure assessment was based on city-wide average $PM_{2.5}$ concentrations and therefore did not capture intra-urban variability in exposure. Individuals residing near major roads or industrial sources may experience substantially higher pollution levels than reflected by the city-wide average. Future studies incorporating higher-resolution exposure assessment methods could better characterize spatial variability in $PM_{2.5}$ exposure and support more geographically refined health impact assessments. Third, the concentration-response functions used in AirQ+ are derived primarily from cohort studies conducted outside Georgia and may not fully represent local population characteristics or exposure patterns. In addition, the analysis did not account for indoor air pollution, socioeconomic factors, behavioral risk factors, or the combined effects of multiple pollutants. Furthermore, the 95% confidence intervals reported by AirQ+ reflect uncertainty in the concentration-response function (relative risk estimates) and do not account for additional sources of uncertainty, including exposure assessment, population estimation, mortality data, or the spatial representativeness of the monitoring network. Consequently, the estimated mortality burden should be interpreted as an approximation of the health impacts attributable to $PM_{2.5}$ exposure. Future studies could extend this work by examining cause-specific mortality outcomes to provide more clinically relevant evidence for public health policy, as well as estimate population-weighted $PM_{2.5}$ exposure at the district level to better account for spatial variation in both pollution concentrations and population distribution across Tbilisi.

The hypothetical reduction scenarios demonstrated substantial potential health benefits

Georgian Biomedical and Medical Nexus (Former Georgian Biomedical News)
ISSN (Online): 2720-8796 ISSN (Print): 2720-7994

associated with improving air quality in Tbilisi. Reducing the long-term mean $PM_{2.5}$ concentration from 17.3 µg/m³ to 12.3 µg/m³ and 7.3 µg/m³ was associated with marked declines in attributable mortality. In contrast, attainment of the WHO annual guideline value of 5 µg/m³ was associated with the elimination of modeled $PM_{2.5}$-attributable mortality above the counterfactual concentration. These findings suggest that even moderate reductions in $PM_{2.5}$ concentrations could prevent a considerable number of premature deaths.

Overall, this study provides one of the first standardized estimates of $PM_{2.5}$-attributable mortality in Tbilisi based on multi-year data. The findings support integrating air-quality improvement into urban health and environmental policy and highlight the importance of interventions targeting major emission sources, particularly traffic emissions, construction-related dust, and residential combustion sources.

CONCLUSIONS

Using the WHO AirQ+ methodology, this study estimates that long-term exposure to $PM_{2.5}$ in Tbilisi, at a six-year mean concentration of 17.3 µg/m³, is associated with a substantial mortality burden among adults aged ≥30 years. Hypothetical reductions in annual $PM_{2.5}$ concentrations by 5 µg/m³ and 10 µg/m³, as well as attainment of the WHO Air Quality Guideline value of 5 µg/m³, would progressively reduce the modeled attributable mortality burden, potentially preventing hundreds to more than one thousand premature deaths annually, depending on the reduction scenario.

Despite several methodological limitations, this analysis provides a credible and policy-relevant estimate of the mortality burden associated with long-term $PM_{2.5}$ exposure in Tbilisi. The estimated attributable fractions and absolute mortality counts offer an evidence-based foundation for local public health and environmental policy interventions. These findings support the need for strengthened air quality management strategies and progressive alignment with WHO guideline values in order to maximize potential population health benefits.

AUTHOR AFFILIATION

1. Department of Hygiene, Medical Ecology and Health Promotion, Tbilisi State Medical University, Tbilisi, Georgia
2. National Center for Disease Control and Public Health, Tbilisi, Georgia

REFERENCES

1. World Health Organization. Air pollution. Accessed May 11, 2026. https://www.who.int/health-topics/air-pollution.
2. Huang W, Xu H, Wu J, Ren M, Ke Y, Qiao J. Toward cleaner air and better health: current state, challenges, and priorities. Science. 2024;385(6707):386-390. doi:10.1126/science.adp7832.
3. World Health Organization. Ambient (outdoor) air pollution: key facts. Accessed May 11, 2026. https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health.
4. Chen J, Hoek G. Long-term exposure to PM and all-cause and cause-specific mortality: a systematic review and meta-analysis. Environ Int. 2020;143:105974. doi:10.1016/j.envint.2020.105974.
5. Kim KH, Kabir E, Kabir S. A review on the human health impact of airborne particulate matter. Environ Int. 2015;74:136-143. doi:10.1016/j.envint.2014.10.005.
6. World Health Organization. Health Effects of Particulate Matter: Policy Implications for Countries in Eastern Europe, Caucasus and Central Asia. Accessed May 11, 2026. https://iris.who.int/items/48ffc09d-5a7b-4a94-bbbb-801b98f57b47.
7. Martin R, Dowling K, Pearce D, Sillitoe J, Florentine S. Health effects associated with inhalation of airborne arsenic arising from mining operations. Geosciences. 2014;4(3):128-175. doi:10.3390/geosciences4030128.
8. Sang S, Chu C, Zhang T, Chen H, Yang X. The global burden of disease attributable to ambient fine particulate matter in 204 countries and territories, 1990–2019: a systematic analysis of the Global Burden of Disease Study 2019. Ecotoxicol Environ Saf. 2022;238:113588. doi:10.1016/j.ecoenv.2022.113588.
9. Hystad P, Larkin A, Rangarajan S, et al. Associations of outdoor fine particulate air pollution and cardiovascular disease in 157 436 individuals from 21 high-income, middle-income, and low-income countries (PURE): a prospective cohort study. Lancet Planet Health. 2020;4(6):e235-e245. doi:10.1016/S2542-5196(20)30103-0.

10. Sandra B. Poverty and Distributional Consequences of Air Pollution in Tbilisi.
11. Kashibadze T, Kiladze N, Ruadze E. Impact of COVID-19 lockdowns on air pollution in Tbilisi. Environ Monit Assess. 2025;198(1):7. doi:10.1007/s10661-025-14883-w.
12. Baquie S, Behrer PA, Du X, Fuchs A, Nozaki NK. Impacts and Sources of Air Pollution in Tbilisi, Georgia. World Bank; 2023. doi:10.1596/1813-9450-10643.
13. World Health Organization. AirQ+: software tool for health risk assessment of air pollution. Accessed May 12, 2026. https://www.who.int/europe/tools-and-toolkits/airq---software-tool-for-health-risk-assessment-of-air-pollution.
14. World Health Organization. WHO Global Air Quality Guidelines: Particulate Matter (PM2.5 and PM10), Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide. Accessed February 23, 2026. https://www.who.int/publications/i/item/9789240034228.
15. World Health Organization. Health Impact Assessment of Air Pollution: Introductory Manual to AirQ+. Accessed May 15, 2026. https://www.who.int/europe/publications/i/item/WHO-EURO-2020-1557-41308-56210.
16. Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. Proc Natl Acad Sci U S A. Accessed May 12, 2026. https://www.pnas.org/doi/full/10.1073/pnas.1803222115.
17. United Nations Serbia. Health impact of ambient air pollution in Serbia: a call to action. Accessed May 13, 2026. https://serbia.un.org/en/22141-health-impact-ambient-air-pollution-serbia-call-action.
18. Naimi N, Sarkhosh M, Nabavi BF, Najafpoor A, Musa Farkhani E. Estimating the burden of diseases attributed to PM2.5 using the AirQ+ software in Mashhad during 2016–2021. Sci Rep. 2024;14(1):24462. doi:10.1038/s41598-024-74328-1