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# ATTRIBUTABLE PREMATURE DEATHS DUE TO LONG-TERM $PM_{2.5}$ EXPOSURE IN IZMIR OVER FIVE YEARS: AN ECOLOGICAL STUDY

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## ABSTRACT

***Objective:*** *This study aims to assess the estimated premature deaths attributable to long-term particulate matter 2.5 (PM2.5) exposure in Izmir from 2019 to 2023.*

***Material and Method:*** *This ecological study utilized air pollution data obtained from the Ministry of Environment and Urbanization, with annual $PM_{2.5}$ averages collected from monitoring stations in Izmir Mortality data and information on the at-risk population were sourced from the Turkish Statistical Institute (TUIK), and the data were analyzed using the WHO's AirQ+ software to estimate health impacts.*

***Results:*** *The study found that none of the annual $PM_{2.5}$ averages from the monitoring stations were below the WHO limit of 10 µg/m³. Between 2019 and 2023, an estimated 16457 (95% CI: 12,571–18,000) premature deaths in Izmir were associated with PM2.5 exposure. On average, 10.77% (95% CI: 8.35–12.08) of annual deaths were attributed to PM2.5, with the highest attributable proportion of 14.2% (95% CI: 10.95–15.76) observed in 2022, and the lowest of 7.27% (95% CI: 5.9–8.6) in 2021.*

***Conclusion:*** *The premature deaths linked to air pollution in Izmir reflect a significant public health burden. The rising pollution levels following the pandemic emphasize the need for sustainable air quality and public health policies. Given Izmir's status as one of Turkey's most populous cities, targeted interventions for densely populated areas and industrial sources are crucial to safeguarding public health, along with the implementation of green infrastructure and environmental measures.*

***Keywords:*** *Air pollution, $PM_{2.5}$, premature deaths, Turkiye, ecological study*

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## İZMİR'DE BEŞ YIL BOYUNCA UZUN DÖNEM $PM_{2.5}$ MARUZİYETİNE BAĞLI ATFEDİLEBİLİR ERKEN ÖLÜMLER: BİR EKOLOJİK ÇALIŞMA


## ÖZET

**Amaç:** Bu çalışma, İzmir'de 2019-2023 yılları arasında uzun süreli partikül madde 2,5 ($PM_{2.5}$) maruziyetine bağlı olarak tahmini erken ölümleri değerlendirmeyi amaçlamaktadır.

**Materyal ve Metot:** Ekolojik tasarımla yürütülen çalışmada, İzmir'deki hava kirliliği verileri Çevre ve Şehircilik Bakanlığı'ndan alınmış, yıllık $PM_{2.5}$ ortalamaları izleme istasyonlarından elde edilmiştir. Ölüm verileri ve risk altındaki nüfus bilgileri TÜİK'ten sağlanmış, veriler DSÖ'nün AirQ+ yazılımıyla analiz edilmiştir.

**Bulgular:** Çalışmada, yıllık $PM_{2.5}$ ortalaması hiçbir istasyonda DSÖ'nün 10 µg/m³ sınırının altında bulunmamıştır. İzmir'de 2019-2023 yılları arasında 16457 (%95 GA: 12571-18000) erken ölüm, $PM_{2.5}$ maruziyeti ile ilişkilendirilmiştir. Ortalama yıllık ölümlerin %10,77'u (%95 GA: 8,35-12,08) $PM_{2.5}$ değerine bağlanmış olup, en yüksek atfedilebilir oran %14,2 (%95 GA: 10,95-15,76) ile 2022'de, en düşük oran ise %7,27 (%95 GA: 5,9-8,6) ile 2021'de gözlemlenmiştir.

**Sonuç:** İzmir'de hava kirliliğine bağlı erken ölümler önemli bir halk sağlığı yükünü yansıtmaktadır. Pandemi dönemi sonrası yükselen kirlilik oranları, sürdürülebilir hava kalitesi ve halk sağlığı politikalarının uygulanmasının gerekliliğini vurgulamaktadır. İzmir, Türkiye'nin en kalabalık şehirlerinden biri olduğundan, yoğun nüfus bölgeleri için hedeflenen önlemler, sanayi kaynaklı kirliliğin azaltılması ve yeşil altyapı gibi çevresel müdahaleler, halk sağlığını korumada büyük önem taşımaktadır.



**Anahtar kelimeler:** Hava kirliliği, $PM_{2.5}$, erken ölümler, Türkiye, ekolojik çalışma.


## INTRODUCTION

Air pollution is one of the most critical environmental health challenges globally, contributing to over 4 million premature deaths annually.[1] A significant portion of these deaths are attributed to severe health conditions such as ischemic heart disease, stroke, chronic and acute respiratory diseases, and various types of cancer.[1]

$PM_{2.5}$, a fine particulate matter with a diameter of less than 2.5 micrometers, exerts harmful health effects through several key mechanisms. Upon inhalation, $PM_{2.5}$ particles penetrate deep into the lungs and enter the bloodstream, triggering oxidative stress, inflammation, and genotoxicity. These processes not only damage lung tissue but also disrupt cardiovascular function and impair the immune system, increasing vulnerability to infections and chronic diseases.[2] As a result, long-term exposure to $PM_{2.5}$ has been linked to serious health outcomes, including ischemic heart disease, stroke, chronic obstructive pulmonary disease (COPD), lung cancer, and increased premature mortality.[3] These findings underscore the urgent need for strategies to reduce $PM_{2.5}$ levels and mitigate its significant public health impacts. Reducing $PM_{2.5}$ levels to 10 µg/m³ could significantly lower premature deaths worldwide.[4]

A nationwide study conducted in 2018 in Turkey assessed attributable premature deaths due to $PM_{2.5}$ exposure across all cities.[5] A subsequent study in 2019 calculated the mortality rates for lung cancer and COPD attributable to long-term $PM_{2.5}$ exposure.[6] However, despite various studies in specific cities over the past five years, no research has specifically examined the relationship between air pollution and attributable premature deaths in Izmir.[7–11] Izmir, one of the largest and most industrialized cities in Turkey, faces significant environmental challenges, particularly related to air pollution. The city's dense population, heavy traffic, and industrial activities contribute to elevated particulate matter levels, making air pollution a critical public health issue.

This study aims to estimate the number of premature deaths attributable to long-term $PM_{2.5}$ exposure in Izmir over a five-year period (2019-2023). By calculating the attributable proportion and the number of cases due to $PM_{2.5}$ exposure for each year, as well as the rate of attributable cases per 100,000 population at risk, we aim to quantify the specific health impact of air pollution on mortality in Izmir. These estimations provide crucial insights to guide future air quality management efforts and public health interventions.

## MATERIALS AND METHODS

This study was designed as an ecological study. The air pollution data used in the research were obtained from the official website of the Ministry of Environment and Urbanization.[12] Annual average $PM_{10}$ and $PM_{2.5}$ data from all monitoring stations in Izmir were collected separately for the five-year period between 2019 and 2023. Stations with

**Table 1.** The annual average PM2.5 values of air monitoring stations located in İzmir (2019-2023)

| Stations | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|
| Aliağa | NA | 34.67 | NA | 29.48 | 22.69 |
| Aliağa-Bozköy | NA | NA | NA | 35.21 | 24.21 |
| Alsancak | 20.60 | 25.09 | 19.84 | 28.43 | 25.41 |
| Bayraklı | 29.60 | 24.83 | 25.67 | 25.87 | 29.30 |
| Bornova | NA | NA | NA | 29.46 | NA |
| Bornova-2 | 27.37 | 24.67 | 27.82 | 28.71 | 30.33 |
| Çeşme | NA | NA | NA | 17.10 | 15.00 |
| Çiğli | 21.63 | 22.95 | 15.54 | 24.39 | NA |
| Eğitim | NA | NA | NA | 46.72 | NA |
| Gaziemir | 23.96 | 30.89 | NA | 33.79 | 24.47 |
| Güzelyalı | 26.97 | 20.85 | 20.73 | 21.20 | 19.14 |
| Karabağlar | NA | NA | NA | 30.58 | NA |
| Karaburun | NA | NA | NA | 29.28 | 20.88 |
| Karşıyaka | NA | NA | NA | 46.09 | NA |
| Karşıyaka-2 | 15.57 | 21.45 | 20.47 | 21.79 | 19.96 |
| Konak | NA | NA | NA | 25.55 | 22.78 |
| Menemen | NA | NA | NA | NA | 32.33 |
| Ödemiş | NA | NA | NA | NA | 31.82 |
| Şirinyer | 20.98 | 22.29 | 12.99 | 18.99 | 21.16 |
| Torbalı | NA | NA | NA | 48.12 | 38.20 |
| Yenifoca | NA | NA | NA | 25.55 | 23.07 |
| Kemalpaşa | NA | NA | NA | 31.72 | 37.58 |

**NA:** Not available

measurements conducted on fewer than 75% of the days in a given year were excluded from the analysis. For the remaining stations, those with annual average $PM_{2.5}$ data were included in the study, and for stations lacking $PM_{2.5}$ data, $PM_{10}$ values were converted to $PM_{2.5}$ using the World Health Organization (WHO)-recommended conversion factor of 0.66327.[13] The $PM_{2.5}$ values from these stations were then averaged by dividing the sum of annual $PM_{2.5}$ data by the number of included stations to calculate the annual average $PM_{2.5}$ levels for Izmir.

The population at risk for each year was calculated by extracting data on individuals aged 30 years and older from the population data by province and age group, as provided by the Turkish Statistical Institute (TUIK).[14] Mortality data for individuals aged 30 and above in Izmir were calculated using death records by province and age group, also obtained from TUIK.[15]

The data were analyzed using AirQ+ 2.2 software, developed by the WHO, to assess the health impacts of air pollution.[13] The cut-off value for air pollution was set at the WHO-recommended annual average of 10 µg/m³.[16] In addition, the relative risk for mortality due to $PM_{2.5}$ exposure among individuals aged 30 and older was included in the analysis, using a relative risk (RR) of 1.08 (95% CI: 1.06-1.09) as recommended by the WHO based on meta-analyses.[16,17]

## RESULTS

In our study, the annual average $PM_{2.5}$ concentration was calculated using the results from eight stations for 2019, nine stations for 2020, seven stations for 2021, 20 stations for 2022, and 17 stations for 2023. Stations with at least two years of average results show that Torbalı, with an annual average $PM_{2.5}$ of 43.16±7.02 µg/m³ and Kemalpaşa, with 34.65±4.14 µg/m³, are the stations with the highest levels. On the other hand, the stations with the lowest pollution levels are Çeşme, with an annual average $PM_{2.5}$ of 16.05±1.48 µg/m³, and Sirinyer, with 19.26±3.71 µg/m³. Additionally, it is observed that none of the 61 annual $PM_{2.5}$ average values obtained from 22 stations over five years were below the WHO-recommended limit of 10 µg/m³ (Table 1).

Over this five-year period, it is estimated that an overall of 10.77% (95% CI: 8.35-12.08) of annual deaths among individuals aged 30 years and older could be attributed to the long-term effects of $PM_{2.5}$ exposure. The year with the lowest estimated attributable proportion was 2021, with 7.27% (95% CI: 5.9-8.6), while the highest was observed in 2022, at 14.2% (95% CI: 10.95-15.76). The estimated attributable number of deaths over the five-year period was estimated at 16.457 (95% CI: 12.571-18.000). The average estimated annual number of attributable cases per 100000 population at risk was found to be 119.8 (95% CI: 91.99-113.18). The estimated attributable proportion and the estimated attributable number of deaths due to long-term $PM_{2.5}$ exposure in Izmir over the years are summarized in Table 2 and Figure.

## DISCUSSION

In our study, we found that the attributable premature death rate due to air pollution in Izmir was 9.9% in 2019, which is similar to the 9.7% reported by Pala *et al*. for 2018.[5] In 2020, an increase of 11.8% was observed, which may be attributed to rising air pollution levels and the addition of a new monitoring station (Gaziemir). However, in 2021, there was a 34.5% reduction in comparison to the previous year. This reduction is consistent with the global decline in air pollution observed during the period of the pandemic associated with the SARS-CoV-2 virus, which is likely attributable to the implementation of lockdowns and changes in human behaviour.[18-20] The

observed increase in 2022 may be attributed to the resumption of activities following the pandemic, as well as an increase in the number of measurements taken in Izmir.[21] In 2023, the attributable death rate returned to 11.4%, a figure similar to that observed prior to the pandemic. However, it is notable that this rate is higher than both the 2019 rate and the 2018 rate reported by Pala *et al*.[5] In order to gain a deeper insight into the changes in the proportion of premature deaths attributable to air pollution in Izmir, it is vital to have a reliable network of monitoring stations that are able to provide consistent coverage of a significant portion of the city and regularly record these data points, particularly as the city begins to return to normalcy following the pandemic.

It is also crucial to emphasize the importance of considering regional differences within Izmir. Areas with higher levels of air pollution often experience increased population movement, which can magnify the public health risks in these regions. Consequently, the implementation of targeted measures for these high-pollution zones is of paramount importance. Specific interventions aimed at these areas would help mitigate the adverse health impacts of air pollution, particularly in densely populated or industrialized regions where the risk of exposure is greater.

In a study covering six provinces in the Marmara region of Turkey, the estimated attributable premature death rate due to air pollution in 2019 was found to range between 6.23% and 11.23%.[8] The 9.3% rate found in our study for Izmir in the same year also appears comparable to these cities. Additionally, a study conducted in Konya reported an estimated attributable premature death proportion of 12.02% for 2019, which is slightly higher than the rate found in Izmir.[10] Although there are many studies on this topic for 2019 and earlier, research on the COVID-19 pandemic and the post-pandemic period in Turkey is limited.[8,10,11,22] Therefore, it has not been possible to compare recent changes in Izmir with other provinces.

Although Izmir has similar attributable proportions to other provinces, being the third most populous city in the country, the estimated attributable cases over the five-year period were found to be 16457. This large number highlights the significant public health burden faced by Izmir due to its population at risk size. As a densely populated metropolitan area, even relatively moderate attributable proportions can translate into a substantial number of premature deaths, underscoring the critical need for targeted air quality interventions to protect the health of its residents.

**Table 2.** Estimated Attributable Proportion and Attributable Cases Due to Long-term $PM_{2.5}$ Exposure in İzmir (2019-2023)

| Year | Estimated attributable proportion (%) | | | Estimated attributable case | | | Estimated attributable case per 100K population at risk | | |
|---|---|---|---|---|---|---|---|---|---|
| | Central | Lower | Upper | Central | Lower | Upper | Central | Lower | Upper |
| 2023 | 11.44 | 8.78 | 12.71 | 3412 | 2621 | 3794 | 121.87 | 93.62 | 135.50 |
| 2022 | 14.20 | 10.95 | 15.76 | 4504 | 3473 | 4999 | 162.77 | 125.5 | 180.64 |
| 2021 | 7.27 | 5.90 | 8.60 | 2568 | 1963 | 2862 | 94.15 | 71.97 | 104.93 |
| 2020 | 11.10 | 8.53 | 12.35 | 3321 | 2481 | 3593 | 120.12 | 92.23 | 133.58 |
| 2019 | 9.93 | 7.61 | 11.05 | 2652 | 2033 | 2952 | 99.95 | 76.63 | 111.24 |
| **Overall** | 10.77 | 8.35 | 12.08 | 16457 | 12571 | 18200 | 120.67 | 92.18 | 133.45 |

It is important to consider the limitations of this study when interpreting the results. Firstly, it should be noted that the present analysis focused solely on $PM_{2.5}$, without taking into account other air pollutants such as nitrogen dioxide or sulfur dioxide, which are also known to have significant health impacts. The exclusion of these pollutants may result in an underestimation of the total health burden attributable to air pollution in Izmir. Secondly, there were changes in the number of monitoring stations across the five-year period, with some years exhibiting a reduction in the number of active stations compared to others. Such variability may impact the consistency and comparability of the data across years. Furthermore, not all monitoring stations were able to provide continuous measurements throughout the entire study period, resulting in some gaps in the data. To ensure the representativeness of the study, stations with less than 75% of the required measurements were excluded from the analysis. A further limitation is the use of the AirQ+ software developed by the WHO. Although this model is widely used and based on well-established methodologies, it still relies on certain assumptions and pre-defined risk factors, which may not fully capture the complexity of real-world air pollution effects. The estimates produced are based on relative risks derived from meta-analyses, which may vary depending on local environmental and health factors that were not specifically addressed

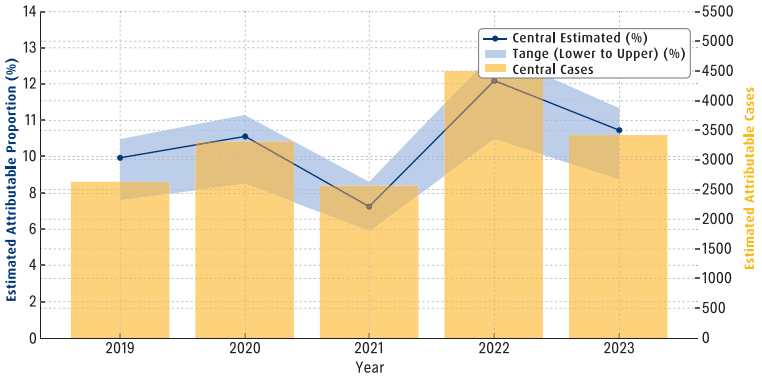


**Figure.** Estimated Attributable Proportion (%) and Cases Due to Long-term $PM_{2.5}$ Exposure Over Years in Izmir (2019-2023)

in this study. Moreover, as an ecological study, our findings represent population-level associations between $PM_{2.5}$ exposure and mortality. This design does not allow us to establish causal relationships at the individual level, nor can we account for other personal factors that might influence susceptibility to air pollution.

## CONCLUSION

The findings of this study indicate that long-term exposure to $PM_{2.5}$ in Izmir is associated with a significant public health burden, with an estimated 16457 premature deaths over the five-year period from 2019 to 2023. Although Izmir exhibits comparable attributable proportions to other Turkish provinces, its substantial population magnitude amplifies the total number of premature deaths, highlighting the imperative for more stringent pollution control measures, particularly in heavily industrialized and densely populated regions.

The observed fluctuations in air pollution levels, particularly during the period of the pandemic and the subsequent return to pre-pandemic activity, emphasize the importance of sustained monitoring of air quality and the implementation of region-specific interventions. The improvement of air quality in Izmir will necessitate the implementation of a multifaceted approach, comprising policy actions and public health strategies that address both local industrial sources and broader environmental factors.

It would be beneficial for future research to focus on the combined effects of multiple pollutants, such as $NO_2$ and $SO_2$, which were not accounted for in this study, in order to gain a more comprehensive understanding of the health impacts of air pollution. Furthermore, studies examining the long-term public health benefits of specific air quality interventions, as well as the role of socioeconomic factors in pollution exposure and vulnerability, are vital for the development of equitable and effective air quality policies. Finally, it is imperative to investigate novel strategies for pollution reduction, such as green infrastructure and cleaner technologies, in order to maintain the progress made in urban air quality and public health.

*The authors declare that there are no conflicts of interest

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