Research Article

Evaluation of the effect of NO₂ levels on mortality in four key cities of Türkiye between 2017-2019

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Abstract

This study aimed to evaluate the NO₂ levels in four key cities of Türkiye (İstanbul, Ankara, İzmir, and Bursa) over three years and examine the effect of NO₂ on mortality and is a descriptive-ecological research. It required each city's air quality (NO₂), population and death data to cover the dates between January 1, 2017, and December 31, 2019. The study accepted 20 $\mu g/m^3$ as the annual NO₂ limit value. Numbers, percentages, mean, standard deviation, and minimum and maximum values were used in summarizing data. Calculations related to mortality attributed to NO₂-induced air pollution were made using the AirQ+ software's methodology. In 2019, 33 stations in İstanbul, four in Ankara, five in İzmir, and five in Bursa measured NO₂. In 2019, the weighted NO₂ mean was 40.61 $\mu g/m^3$ in İstanbul, 32.94 $\mu g/m^3$ in Ankara, 7.87 $\mu g/m^3$ in İzmir, and 31.68 $\mu g/m^3$ in Bursa. The estimated percentage of deaths attributed to NO₂ in 2019 was 7.95 in İstanbul, 5.07 in Ankara, and 4.58 in Bursa. No calculations were made for 2018 in Ankara and 2017, 2018, and 2019 in İzmir, as the NO₂ levels in these cities were less than 20 $\mu g/m^3$ in the years in question. The results revealed that the NO₂ levels were higher than the limit value in three of the four key cities in Türkiye and that the mortality rates attributed to NO₂ were higher compared to similar studies in the literature.

Keywords: air pollution, AirQ+, nitrogen oxide, NO₂, Türkiye

1. Introduction

Air pollution, accepted as one of the top ten risk factors threatening human health, is the most critical environmental factor threatening health (1, 2). Increasing air pollution levels can increase the burden of heart disease, stroke, lung cancer, and acute and chronic respiratory diseases. It is estimated that there were 4.2 million deaths in 2016 due to air pollution in rural and urban areas (1). 91% of the world population lives in places where the air quality limit values of the World Health Organization are exceeded (3).

According to the Global Burden of Disease study, 11.80% of all deaths and 8.40% of DALYs (Disability-adjusted life years) worldwide in 2019 are associated with air pollution (4). In the same study, air pollution in Türkiye increased by 3.5% between 2009 and 2019, making it the fifth most common cause of death and disease in 2019 (5). Reducing diseases and deaths due to air pollution, using clean energy sources in houses, and reducing the environmental burden of cities by improving air quality are among the United Nations Sustainable Development Goals (6, 7).

Nitrogen dioxide (NO₂) is one of the nitrogen oxides and a

reactive gas that is an important cause of air pollution. NO2 is produced as a result of the combustion of fuels. The main source of this pollutant is exhaust emissions and power plants (8). High doses of NO2 can aggravate respiratory diseases and increase hospital admissions and emergency room visits (1, 8). It is known that long and short-term NO2 exposures cause mortality (9, 10). There are also research cohorts showing the association of NO2 with increased mortality (11, 12).

This research aimed to evaluate the NO₂ levels in the three years covering 2017-2019 and examine the effect of NO₂ on mortality in Türkiye's four most densely populated provinces (İstanbul, Ankara, İzmir, and Bursa).

2. Materials and Methods
2.1. Introduction of the Working Area
Türkiye is located in the European Region of the World Health Organization, has lands in Asia and Europe, and is in the upper-middle economic class (Fig. 1 and 2). The research was conducted in the four key cities of Türkiye. One-third of Türkiye's population lives in these four cities.

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Fig. 1. Türkiye's Location in the World

Fig. 2. The Four Key Cities of Türkiye (İstanbul, Ankara, İzmir, and Bursa) that are the subject of this research

2.2. Type of Research and Research Permits

This is a descriptive-ecological research. Ethics committee approval was obtained from Ankara University Health Sciences Ethics Committee (Number: 05-54, Date: 07.03.2022).

2.3. Research Data

This research was carried out between November 1, 2021, and June 15, .2022. This study required provincial air quality, population, and death data. The NO_2 levels, one of the air quality data, were obtained from the official website of the Turkish Republic of the Ministry of Environment and Urbanization, covering the dates between January 1, 2017, and December 31, 2019 (13), and the province-based population and death data for the years 2017, 2018 and 2019 were obtained from the Turkish Statistical Institute (14). The crude death rate per hundred thousand people was calculated by excluding those caused by poisoning and injury from the number of deaths in the relevant years. It is stated in the annual report of the Right to Clean Air Platform, created by the gathering of sixteen non-governmental organizations, that the levels of air pollutants, including NO_2, are not adequately measured throughout Türkiye (15). For this reason, the data of all air quality measurement stations that measure NO_2 value was used in the study.

2.4. Data Evaluation

The World Health Organization Regional Office for Europe has developed a software called AirQ+ to determine the effects of air quality on mortality and morbidity. AirQ+ is used to quantify air pollution parameters' effects on a specified population's health. The software is used to evaluate the impact of long- and short-term exposure to ambient air pollution and long-term exposure to household air pollution. All calculations performed with AirQ+ software are based on methodologies and concentration-response functions established by epidemiological studies. The baseline concentration-response functions are based on systematic review and meta-analysis studies (16).

For the data required by the AirQ+ software, in order to calculate the annual means of NO₂ levels, the NO₂ levels of the stations that made the NO₂ measurement in the relevant year were weighted according to the measurement frequency of the air quality station and divided by the number of stations. In addition, the population at risk in the relevant year and the crude death rate per hundred thousand people were entered the software. The relative risk value (1041, 95% CI 1019-1064) suggested by the AirQ+ software for NO₂ was used. In the study, the limit value of 20 µg/m³, which is the annual limit value recommended in the 2013 'Health Risks of Air Pollution in Europe' (HRAPIE) project, was accepted as the NO₂ limit value (17). 10 µg/m³, which is the current value of WHO as of September 2021, was not used as a limit value since it was determined after the date of the data within the study (1). The annual NO₂ limit value determined in Türkiye is 40 µg/m³ (18).

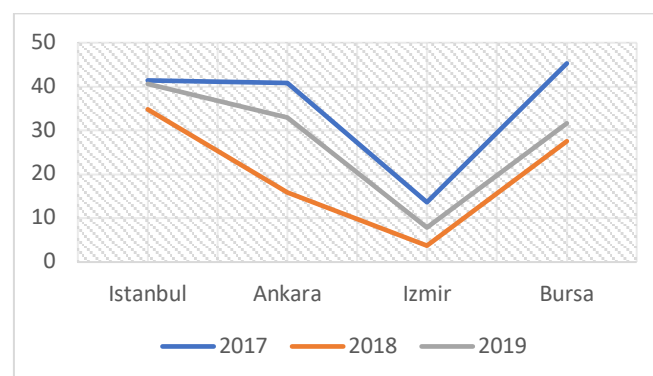Descriptive statistics from the analyzes related to the study

were calculated using manual methods. Other statistics were performed in the computer environment using AirQ+ software. Numbers and percentages were used to summarize categorical data, while mean, standard deviation, and minimum and maximum values were used to summarize numerical data. Calculations related to mortality attributed to NO2-induced air pollution were made using the AirQ+ software's methodology.

3. Results
3.1. Population and Death
The population of İstanbul was 15.029.231 in 2017, 15.067.724 in 2018, and 15.519.267 in 2019. İstanbul's crude death rate per hundred thousand people was calculated as 387.744 in 2017, 398.819 in 2018, and 399.123 in 2019. Population, the number of deaths, and crude death rates per hundred thousand people in İstanbul, Ankara, İzmir, and Bursa by years are shown in Table 1.

Table 1. Population, Number of Deaths, and Crude Death Rates per Hundred Thousand Persons in İstanbul, Ankara, İzmir, and Bursa by Years

City	Year	Population	Total number of deaths	Number of deaths caused by poisoning and injury	Crude death rate per hundred thousand people
İstanbul	2017	15.029.231	59.921	1.646	387.744
	2018	15.067.724	62.547	2.454	398.819
	2019	15.519.267	63.371	1.430	399.123
Ankara	2017	5.445.026	25.413	1.111	446.316
	2018	5.503.985	26.115	1.189	452.872
	2019	5.639.076	26.405	956	451.297
İzmir	2017	4.279.677	25.756	960	579.390
	2018	4.320.519	26.471	1.101	587.198
	2019	4.367.251	27.567	1.030	607.636
Bursa	2017	2.936.803	16.309	714	531.020
	2018	2.994.521	16.636	742	530.769
	2019	3.056.120	16.697	652	525.012

3.2. NO₂ Measurements and Means
The number of stations measuring NO₂ in İstanbul was 12 in 2017 and 2018, and 33 in 2019. The weighted NO₂ mean in İstanbul was 41.39 in 2017, 34.81 µg/m³ in 2018, and 40.61 µg/m³ in 2019. For each city, the number of stations making measurements and the weighted NO₂ means calculated by the measurement percentages of the stations are presented in Table 2.

Table 2. Number of Stations Making Measurements in İstanbul, Ankara, İzmir, and Bursa by Years and Weighted NO₂ Means

City	Year	Number of stations	Weighted NO₂ mean (µg/m³)
İstanbul	2017	12	41.39
	2018	12	34.81
	2019	33	40.61
Ankara	2017	4	40.88
	2018	4	15.90
	2019	4	32.94
İzmir	2017	3	13.64
	2018	10	3.74
	2019	5	7.87
Bursa	2017	5	45.28
	2018	5	27.56
	2019	5	31.68

The trend of NO₂ levels from 2017 to 2019 showed (Fig. 3)

no clear increase or decrease. Some decreases and increases do not follow a certain trend from year to year and from city to city.

Fig. 3. Change of NO₂ by Years in İstanbul, Ankara, İzmir and Bursa

3.3. Deaths Attributed to NO₂
The number of deaths attributed to NO₂ pollution in İstanbul was 4799 (2300-7242) in 2017, 3472 (1652-5275) in 2018, and 4923 (2357-7434) in 2019. The estimated percentages of deaths attributed to NO₂ were 8.24 in 2017, 5.78 in 2018, and 7.95 in 2019 (Table 3). Calculations of 2018 for Ankara and 2017, 2018, and 2019 for İzmir were not made because NO₂ levels were less than 20 µg/m³ in these years.

Table 3. Number of deaths attributed to NO₂ air pollution in İstanbul, Ankara, İzmir and Bursa by year

City	Year	Estimated Number of Attributed Deaths (Min-Max)	Estimated Number of Attributed Deaths Per Hundred Thousand (Min-Max)	Estimated Percentage of Attributable Deaths (Min-Max)
İstanbul	2017	4799 (2300-7242)	31.93 (15.30-48.18)	8.24 (3.95-12.43)
	2018	3472 (1652-5275)	23.04 (10.96-35.01)	5.78 (2.75-8.78)
	2019	4923 (2357-7434)	31.72 (15.19-47.90)	7.95 (3.80-12.00)
Ankara	2017	1956 (937-2952)	35.92 (17.20-54.22)	8.05 (3.85-12.15)
	2018	-	-	-
	2019	1289 (612-1963)	22.87 (10.86-34.81)	5.07 (2.41-7.71)
İzmir	2017	-	-	-
	2018	-	-	-
	2019	-	-	-
Bursa	2017	1506 (725-2264)	51.29 (24.67-77.08)	9.66 (4.65-14.51)
	2018	476 (225-728)	15.88 (7.50-24.32)	2.99 (1.41-4.58)
	2019	736 (349-1121)	24.07 (11.42-36.70)	4.58 (2.17-6.99)

4. Discussion

There is epidemiological evidence of the health effects of air pollution. The World Health Organization reported deaths attributed to ambient air pollution as age-standardized for both sexes per hundred thousand people as 46.57 (40.17-53.31) for Türkiye, 13.31 (9.51-17.78) for the USA, 46.24 (36.87-57.21) for Russia, and 66.73 (57.74-75.79) for China, 109.4 (96.73-124.2) for India, 13.75 (10.15-18.21) for UK, 6.96 (4.63-9.8) for Canada, 24.06 (19.3-30.22) for Brazil, 113.18 (9.51-17.38) for Denmark, 66.55 (54.05-79.37) for the Democratic Republic of Congo and 8.39 (5.9-11.81) for Australia in 2016 (19). Attributable to ambient air pollution DALYs (Disability-adjusted life years) for the same year for both sexes per hundred thousand were reported that 1,175 (1.041-1.320) for Türkiye, 333 (249.1-430.4) for the USA, 1,131 (953.1-1.315) for Russia, 1.475 (1.291-1.652) for China, 3.038 (2.700-3.413) for India, 300.3 (235.2-381.9) for the UK, 152.1 (109.9-200.8) for Canada, 591 (484.1-723.2) for Brazil, 271.3 (200.7-350.5) for Denmark, 2.179 (1.647-2.715) for the Democratic Republic of the Congo, and 175.2 (131.4-225.7) for Australia (20). According to the Global Burden of Disease study 2019, 11.80% of all deaths and 8.41% of all DALYs worldwide; 9.70% of all deaths and 5.72% of all DALYs in Türkiye are caused by air pollution (21, 22).

There is also evidence showing the health consequences of exposure to NO₂. NO₂ exposure results in an increased risk of lower respiratory tract infections in children (23), is associated with the development of COPD (24), causes the development of childhood asthma (25), causes asthma attacks in both children and adults (26), and may cause lung cancer (26, 27) and increases all-cause mortality (9, 28). A Danish cohort study found a relationship between NO₂ and cardiovascular mortality (29). A meta-analysis of thirteen studies found a relationship between NO₂ exposure and breast cancer (30). A systematic review study evaluating thirteen studies determined that exposure to air pollutants, including NO₂, increases the risk of dementia (31). In a systematic review including fifteen studies, NO₂ was found to be a trigger on the spread and lethality of Covid-19 (32).

In this study, NO₂ measurements in the four key cities of Türkiye were higher than the limit value, excluding every three years in İzmir and in 2018 in Ankara. The trend of NO₂ levels from 2017 to 2019 showed no clear increase or decrease. Some decreases and increases do not follow a certain trend from year to year and from city to city. A study conducted in northern China determined that NO₂ was in a decreasing trend (33). In studies conducted in Portugal, Northwest China, Spain, and India, it was found that NO₂ showed irregular decreases and increases (34-37). In addition, there are studies showing that NO₂ levels decrease during the Covid-19 pandemic period (38-40). Since the main source of NO₂ is exhaust emissions and power plants, this result can be explained by reasons such as traffic density and energy need. This may also be related to the location of the station, the number of measurements, and its accuracy.

The deaths attributed to NO₂ for 2019 in the research are 7.95% in İstanbul, 5.07% in Ankara, and 4.58% in Bursa. Since the measured and recorded NO₂ values in İzmir are below 20 μg/m³, no deaths were attributed to NO₂. In studies conducted in other cities in Türkiye, deaths attributed to NO₂ were 9.5% for Konya in 2019, 18.9% for Erzurum in 2018, 5.57% for Kocaeli in 2018, 3.98% for Sakarya in 2018, 2.61% for Bilecik in 2018, 2.18% for Edirne in 2018 and 0.89% for Balıkesir in 2018 (41-43).

Among the studies conducted in Iran, the rate of deaths attributed to NO₂ was 1.03% for Isfahan in 2013-2014, 2.08% for Mashhad in 2015-2016, and 1.37% short-term exposure and 14.39% long-term exposure for Ahvaz in 2014-2017 (44-46). In a study conducted in North China, the rate of deaths attributed to NO₂ was 4.19%, and in a study conducted in Northwest China, it was calculated as 1.57% (33, 35). In another study in northern Italy, the rate of deaths attributed to NO₂ was 1.8% (47). There are lower percentages in the literature than the frequency of deaths attributed to NO₂ obtained in the current study. This situation may depend on the distance of the buildings to the highways, the type and amount of energy used in the houses, and the policies implemented or not implemented by the countries regarding reducing air pollution.

Our research evaluated the NO₂ values and the deaths attributed to NO₂ in the four key cities in Türkiye. To our

knowledge, this is the first study to evaluate four key cities in Türkiye. Since the research was conducted using the latest death data in Türkiye, it provides up-to-date information. These two situations are the highlights of the research.

Since the research is of ecological type, it does not evaluate the individual, but the geographical location and the society in that region. Both our study and other air quality-related studies in the literature are affected by the number of measuring stations, the location of the station (the distance to the highway, the power plant, etc.), and the number and quality of measurements. Therefore, such studies should be interpreted by taking this information into account. In cities where millions live, relatively few stations have measured and recorded NO_2. These are the limitations of the research.

As a result of the research, it is determined that the NO_2 levels were higher than the determined limit values in three of the four big cities in Türkiye, and the mortality rates attributed to NO_2 were higher compared to similar studies in the literature. It has to be considered that deaths due to air pollutants are preventable deaths. It should be ensured that measures are taken on an international, national and local basis and that air pollutant levels are measured in appropriate localizations, in sufficient numbers, and at acceptable quality. In addition, it is recommended to carry out actual research involving other cities/more cities both from Türkiye and around the world with AirQ+ software to keep the subject up to date and follow the situation.

Ethical statement
Ethics committee approval was obtained from Ankara University Health Sciences Ethics Committee (Number: 05-54, Date: 07.03.2022).

Conflict of interest
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Authors' contributions
Concept: E.N.Y.O., Design: E.N.Y.O., M.O., Data Collection or Processing: E.N.Y.O., M.O., Analysis or Interpretation: E.N.Y.O., Literature Review: E.N.Y.O., M.O., Writing: E.N.Y.O., M.O.

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