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Original Article

Persistent Ambient Air Pollution in Turkey: A 4-Year Analysis

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Abstract

OBJECTIVE: Ambient air pollution is an important cause of morbidity and mortality for both individual and public health. The major contaminant that creates air pollution in Turkey is particulate matter. This study aims to demonstrate Turkey's air quality in terms of particulate matter in the last 4 years.

MATERIAL AND METHODS: In this descriptive study, the public data of the National Air Quality Monitoring Network between the years 2016 and 2019 were analyzed for particulate matter (PM_{10}). Stations with less than 75% data throughout the year were excluded from the evaluation while calculating the annual average values. The averages of the years were compared statistically with each other.

RESULTS: For 111 stations that made sufficient measurements for 4 years, the annual median value of particulate matter remained constant in 12 stations (10.8%), increased in 26 stations (23.4%), and decreased in 73 stations (65.7%). The level of air pollution at 18 stations has been sustained for 4 years. It has been observed that there is no significant improvement in the criterion that the daily average PM_{10} level should not be higher than 50 μg/m^3 for more than 35 days, and pollution is detected above the limit value permitted by the World Health Organization in all provinces and stations except a few provinces every year. Finally, during the 4-year observation, the number of stations that did not make sufficient measurements throughout the year has been found to increase over the years.

CONCLUSION: Our data reveal that the air pollution attributable to particulate matter in Turkey between the years 2016 and 2019 did not regress prominently. On the contrary, air pollution has been found to gain permanency in certain provinces, and air quality monitoring has been inadequate due to insufficient measurement activities of some of the stations.

KEYWORDS: Air pollution, particulate matter, Turkey
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INTRODUCTION

World Health Organization (WHO) reports that 92% of the world population breathes unhealthy air that is polluted above the limit values permitted by the WHO.[1] Particulate matter, ozone, carbon monoxide, nitrous oxide, and sulfur oxide, which are produced by traffic emissions, energy power plants, and industrial activities, are the main outdoor air polluters.[2,3]

Particulate matters (PM) are widespread air polluters that consist of solid and liquid particles in the air. Particulate matters can spread directly in the air (primary PM) or can emerge in the atmosphere through precursors of various gases. Particulate matters can be produced by anthropogenic activities such as factories, energy facilities, burning facilities, construction but can also originate from natural activities. The main chemical elements of PM are sulfates, nitrates, ammonium, and other inorganic ions such as sodium, potassium, calcium, magnesium and chlorine, organic and elemental carbon, shelled materials, particle-bound water, and heavy metals.[4] Particles are defined in terms of their aerodynamic diameter, such as PM_{10} (particles with aerodynamic diameters less than 10 μm) or $PM_{2.5}$ (particles with aerodynamic diameters less than 2.5 μm). Particulate matter is commonly sampled and defined by its mass concentration (μg/m^3) according to its aerodynamics. The negative impact of PM on health is directly related to its aerodynamic diameter. Especially fine particles ($PM_{2.5}$) with an aerodynamic diameter of fewer than 2.5 microns bypass the defense mechanisms of the upper respiratory tract and reach the lung alveoli and then move into the systemic circulation.[5]

As of 2019, although there are 350 stations in the National Air Quality Monitoring Network connected to the Turkish Ministry of Environment and Urbanization, only 69 stations measure $PM_{2.5}$. For this reason, analysis of limited data on $PM_{2.5}$ cannot yield a sufficient estimate for the country. World Health Organization recommends using PM with an aerodynamic diameter of fewer than 10 microns (PM_{10}) to monitor air quality in cases where $PM_{2.5}$ cannot be monitored extensively.[6]

Although there are studies that analyze the air quality in Turkey for years,[7-15] there is a limited number of studies that inquire the kind of change the air quality exhibits throughout the years, as our study does. However, the observation and analysis of change in the air quality of Turkey are significant for both showing the effectiveness of the preventive mechanisms put in place for the matter and shaping the strategy for the improvement of air quality. This study aims to demonstrate Turkey's air quality in terms of PM on a provincial basis in the last 4 years.

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MATERIAL AND METHODS

In this descriptive study, the public data provided by the National Air Quality Monitoring Network connected to the Turkish Ministry of Environment and Urbanization[16] have been analyzed concerning the PM_{10} based on provinces between the years 2016 and 2019. Stations with data less than 75% throughout the year were left out from the evaluation. Data originating from a measurement of more than 75% throughout the year have been used in calculations following the European Environment Agency's qualification definition.[17] The annual average of each year has been statistically compared to reveal the changing trend of air quality. No ethics approval or any institutional permission was necessary or required for this type of study since the data were already existing, open to public, and anonymized.

Data related to PM_{10} starting from January 2016 and for 4 years after have been extracted, organized through LibreOffice Calc 7.0, and sorted out by means of R programming language and R Studio IDE. After these steps, a single file has been formed which included the data of stations with measurements more than 75% of the year. Then, data have been grouped into years, months, and provinces by using R Studio. Shapiro—Wilk's Test was used to see whether the data conformed to a normal distribution, and medians for each group have been found and used for statistical analysis and graphics. The median, highest, and lowest values of each general group and sub-group have been calculated using R Studio and defined in tables. All stations have been grouped into their specific region to avoid generalization, and data have been shown in bar and line graphics for each year and region. Different graphs were used to reveal the trends of increase, decrease, and stability to avoid data confusion.

RESULTS

In 2016, there were 199 observation stations, 4 mobile and 195 immobile, and all of them measured PM_{10}. However, 30 of 199 stations (15%) had measurements less than 75% of the year. Therefore, 169 stations were included in the evaluation. Stations in Muş (126 μg/m^3), Ağrı (Doğubeyazıt) (109 μg/m^3), Iğdır (106 μg/m^3), Kayseri (Hürriyet) (103 μg/m^3), and Tekirdağ (Merkez) (102 μg/m^3) were found to record the highest levels of daily PM. When the three prominent cities were considered, Ankara's daily average (66 μg/m^3) was above the national limit value, while Istanbul and Izmir's daily averages (46 μg/m^3 and 41 μg/m^3, respectively) were below the national limit value. The daily average PM_{10} value was higher than 50 μg/m^3 for more than 35 days per year at 163 of 169 stations (96%) where adequate measurements were made. In 2016, 51% of the stations (86 stations) recorded air pollution above the national limit value and 98% (165 stations) above the WHO in terms of PM_{10}. In the same year, PM_{10} measurements made at the Artvin, Tunceli, Çanakkale (Biga), and Adana (Doğankent) stations were below the limit value permitted by the WHO. However, according to the 24-hour average values, the PM_{10} level at all stations was above the WHO limit value. As of 2016, the national legislative limit value was 52 μg/m^3 (Figure 1).

In 2017, 203 stations were active on air quality observation nationwide. Although all stations measured PM_{10}, only 180 of the stations (89%) held data for more than 75% of the year. There were not enough data to analyze the provinces of Muş, Şırnak, and Uşak. The highest values were found in Amasya (Şehzade) (319 μg/m^3), Bursa (316 μg/m^3), Manisa (314 μg/m^3), Adana (Meteoroloji) (309 μg/m^3), Denizli (Bayramyeri), and Niğde (289 μg/m^3) stations. Of the 180 stations with sufficient data, 156 stations (87%) recorded daily PM_{10} average values above 50 μg/m^3 for more than 35 days in the year. In 2017, the PM_{10} values in all the stations except for the one in Artvin (99.4%) were above the value set by the WHO. The nationally regulated limit value was 48 μg/m^3 in 2017 and it was exceeded in 52 provinces (66.6%) (Figure 2).

In 2018, 163 of the 211 stations that were active nationwide (77%) held data for more than 75% of the year. There were not enough data to analyze the provinces of Bolu, Eskişehir, Kastamonu, Kırıkkale, Kütahya, Muş, Şırnak, and Uşak. Of the 30 stations in Istanbul, 9 stations (30%) conducted sufficient measurements. The highest PM levels were found in Kahramanmaraş (Elbistan) (125 μg/m^3), Iğdır (123 μg/m^3), Bursa (99 μg/m^3), Adana (Meteoroloji), Manisa (94 μg/m^3), and Düzce (Akçakoca) (85 μg/m^3) stations. In 2018, PM_{10} values in all of the stations except for the one in Ardahan (98,6%) exceeded the limit value set by the WHO. Of the 163 stations with sufficient data, 154 stations (94.5%) recorded daily PM_{10} average values above 50 μg/m^3 for more than 35 days in the year. The nationally regulated limit value was 44 μg/m^3 in 2018 and it was exceeded in 41 provinces (56.1%) (Figure 3).

In 2019, there were 338 stations active in air quality observation nationwide. Although all the stations measured PM_{10}, only 177 of them (52%) held data for more than 75% of the year. The proportion of stations that made measurements for more than 75% of the year were 78% in Istanbul, 44% in Bursa, 40% in Izmir, 30% in Ankara and Zonguldak, 29% in Denizli and Konya, 22% in Manisa, 14% in Gaziantep and Muğla. There were no enough data for the analysis of Ağrı, Artvin, Batman, Bayburt, Bolu, Mersin, Tunceli, and Uşak. The highest values of PM_{10} were found in Muş (136 μg/m^3), Afyonkarahisar (89 μg/m^3), Iğdır (87 μg/m^3), Şırnak (81 μg/m^3), and Kahramanmaraş (75 μg/m^3) stations. In 2019, the limit

MAIN POINTS

- Air pollution caused by particulate matter is a significant problem in Turkey. Air quality has not improved in Turkey between 2016 and 2019, even worse, pollution has become permanent in some regions.
- Most air quality observation stations in Turkey do not conduct adequate measurements which lead to the inability to observe pollution caused by $PM_{2.5}$ and the national regulations still do not identify a $PM_{2.5}$ limit value.
- An adequate analysis of air quality in Turkey is not possible due to the inadequate measurements conducted by the air quality observation stations.
- Data on Turkey's mortality and morbidity and disease burden on a provincial and district basis are not available which hinders the putting forward of the causal relationship between pollution and disease/death.

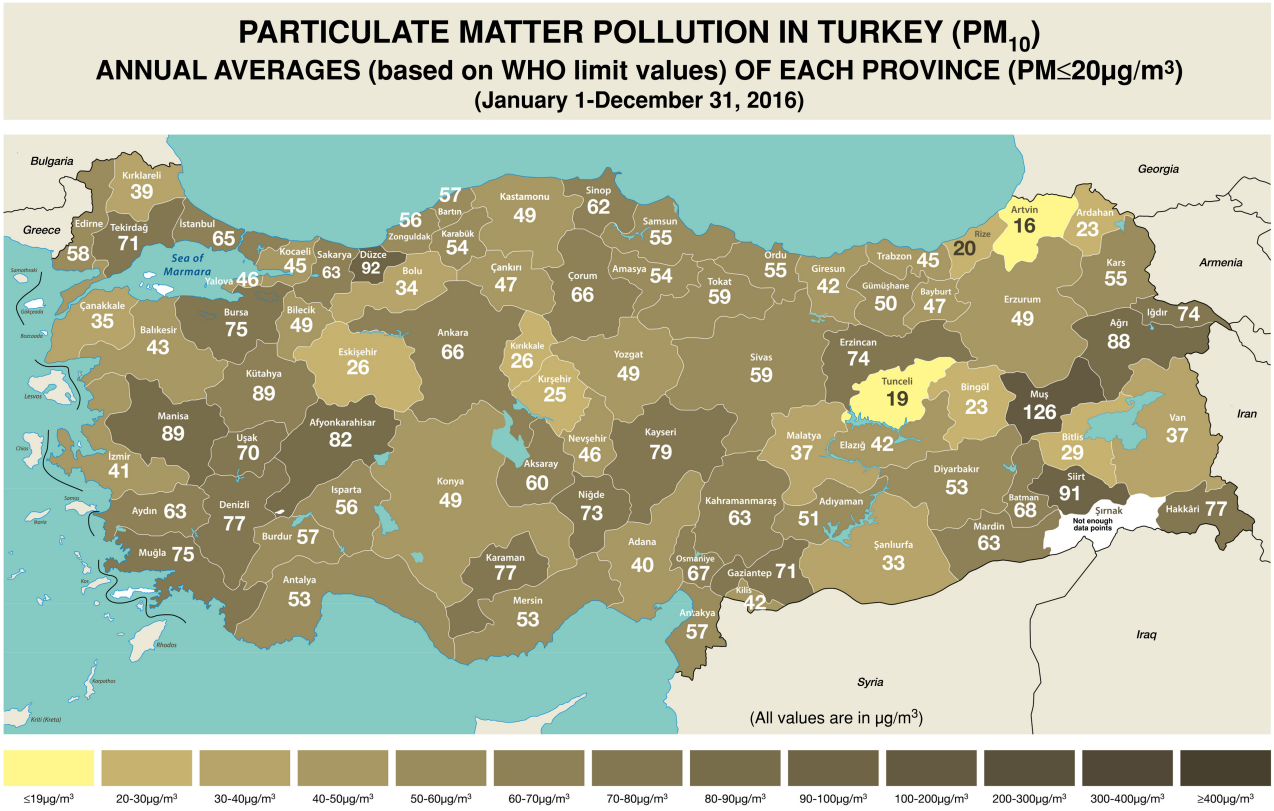


Figure 1. Particulate matter (PM) pollution in Turkey in 2016 (in accordance with the WHO limits).

value permitted by the WHO was exceeded in all the stations except for the ones in Hakkâri and Hatay (99.4%). The national limit value in 2019 was 40 µg/m^3 and it was exceeded in 52 provinces (71.2%) (Figure 4).

When the years between 2016 and 2019 are considered together, it has been found that out of 111 stations that consistently held enough data, 12 of the stations (10.8%) recorded stable median values of PM, 26 of the stations (23.4%)

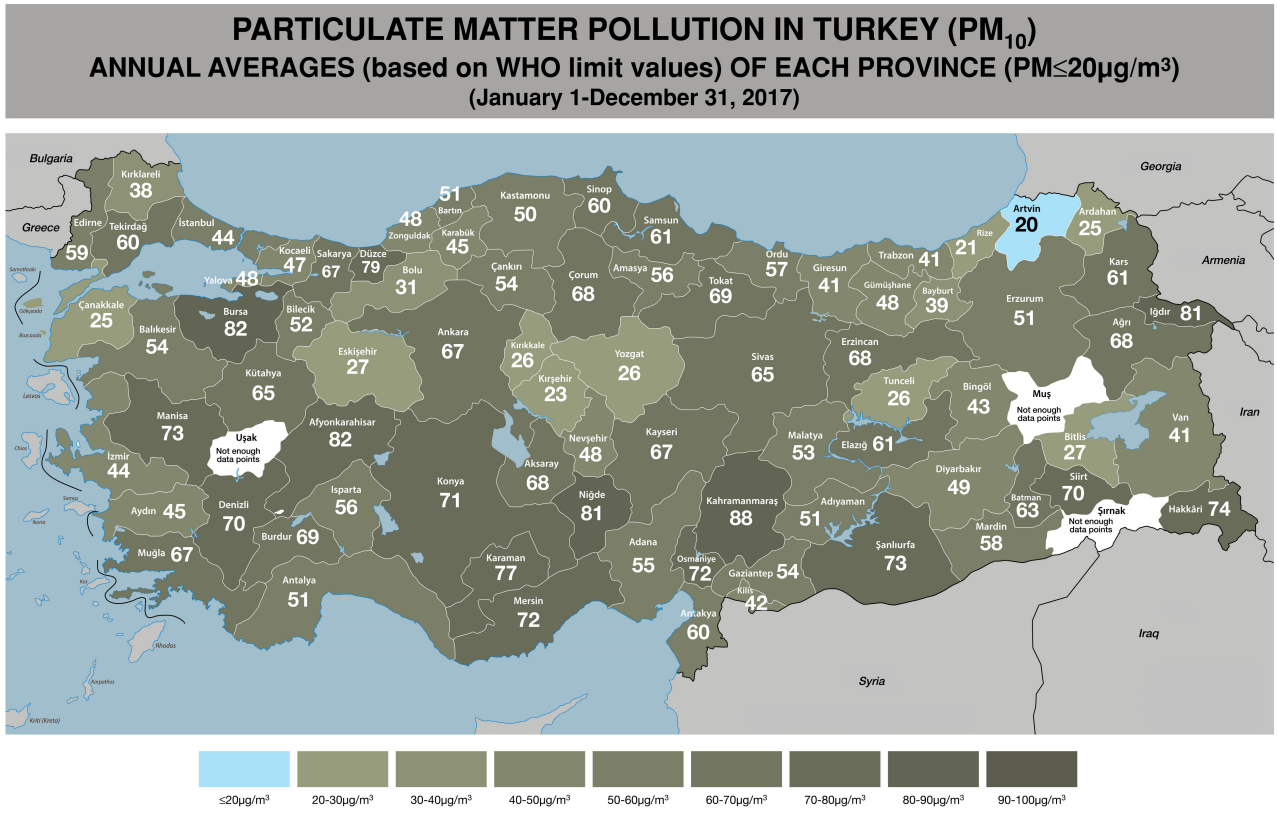


Figure 2. PMarticulate matter pollution in Turkey in 2017 (in accordance with the WHO limits).

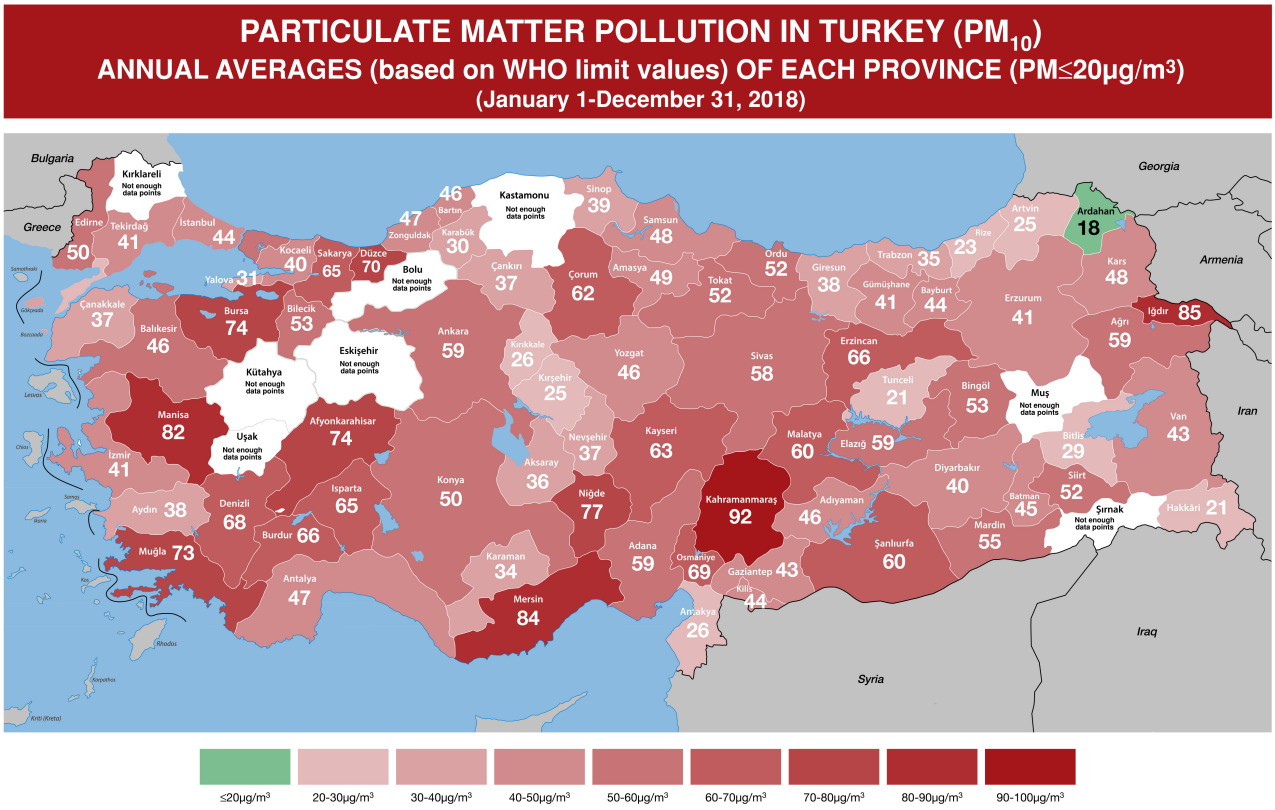


Figure 3. Particulate matter pollution in Turkey in 2018 (in accordance with the WHO limits). WHO, World Health Organization.

recorded increasing median values, while the remaining 73 stations (65.7%) recorded decreasing median values. On the other hand, 18 of the 111 stations (16.2%) recorded persistent air pollution throughout these 4 years (Table 1).

Similarly, the observations reveal that there has not been an improvement in the criteria of daily average PM_{10} level which should not be above 50 µg/m³ for more than 35 days in a year, and the levels measured by almost all stations except

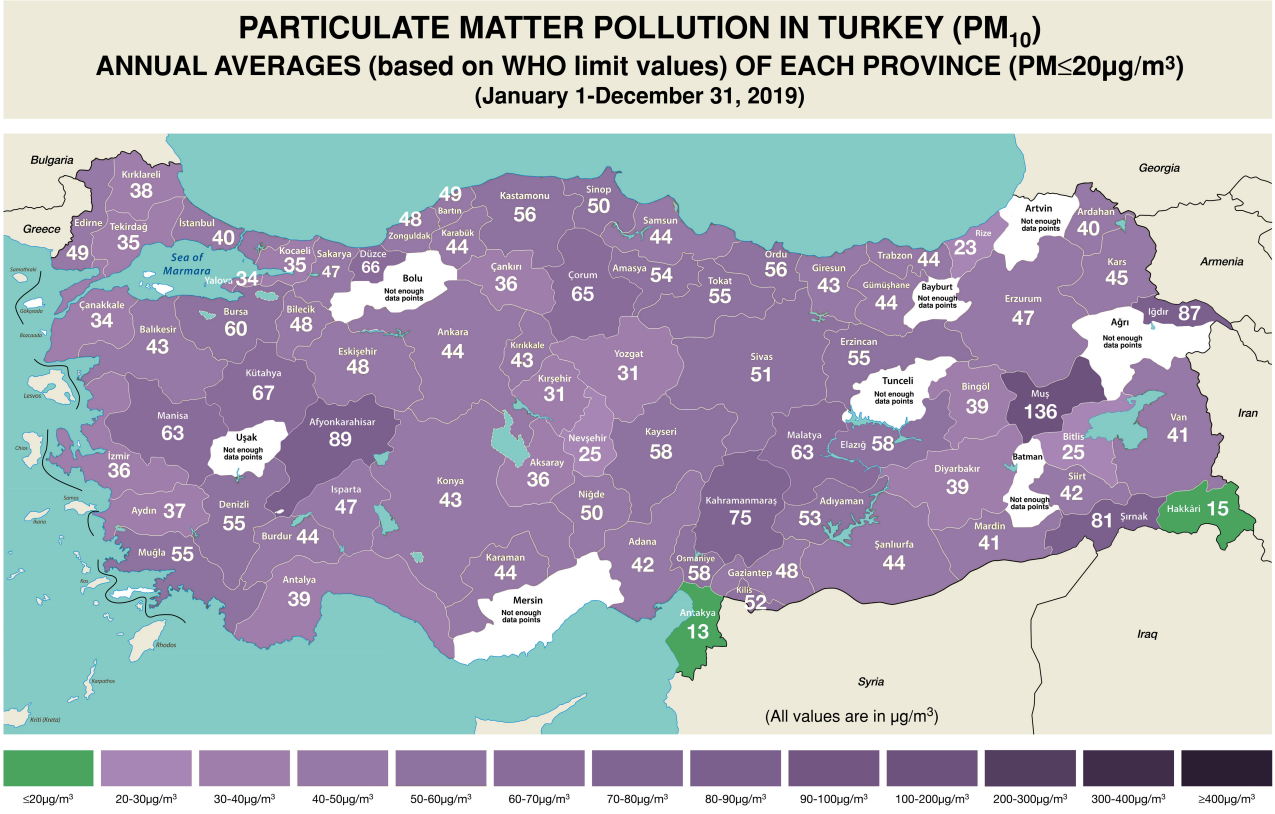


Figure 4. Particulate matter pollution in Turkey in 2019 (in accordance with the WHO limits). WHO, World Health Organization.

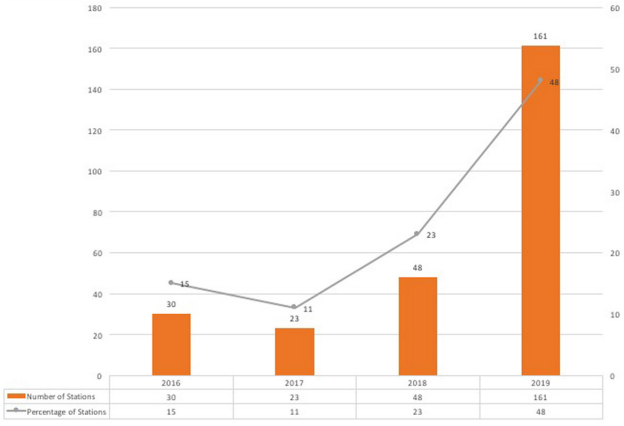
Table 1. Stations Measuring Persistent Air Pollution

Name of the Station	Particulate Matter 10 (μg/m³)*			
	2016	2017	2018	2019
Adana Valilik	52	56	56	51
Adıyaman	44	39	39	48
Bilecik – Bozüyük (MTHM)	46	51	56	51
Bursa	75	90	85	75
Çorum – Mimar Sinan	51	51	52	65
Edirne	42	41	41	43
Elazığ	36	56	49	50
Erzurum – Taşhan	59	60	55	58
Giresun	37	41	43	48
Iğdır	72	115	102	86
İstanbul – Mecidiyeköy (MTHM)	46	43	50	58
Kahramanmaraş	46	48	45	57
Kahramanmaraş – Elbistan	58	91	101	67
Kilis	39	33	33	50
Kocaeli	51	49	57	49
Kocaeli – Ali Kahya (MTHM)	44	47	42	42
Malatya	31	36	47	56
Sivas – Meteoroloji	42	41	49	41

*Annual median value.

for a limited amount of them remained above the limit value permitted by the WHO between the years 2016 and 2019. On the other hand, the number of stations that did not have enough data collected throughout the year seemingly increased in 4 years of observation conducted for this study (Graph 1).

Last but not least, there were 12 provinces in which the level of air pollution consistently ameliorated over the course of four years. These provinces were Antalya, Aydın, Denizli, Diyarbakır, Düzce, Erzincan, Hakkari, İstanbul, Kayseri, Mardin, Siirt and Tekirdağ. In the same period, air pollution level gradually deteriorated in 5 provinces, namely Iğdır, Kırıkkale, Kilis, Malatya, and Rize. For the rest, the trend was either inconsistent or there were missing data.



Graph 1. Number of stations which collect insufficient data (2016-2019).

DISCUSSION

This research reveals that the air pollution level of Turkey constitutes a public health problem that concerns the whole country. The air pollution issue has not improved nationwide between the years 2016 and 2019, on the contrary, it gained permanency in certain regions. In addition, insufficient measuring operations of the stations point out that air quality monitoring is inadequate.

Air pollution is one of the preventable public health problems that cause global morbidity and mortality. Research has shown that children, seniors, pregnant women, and other vulnerable populations are more easily damaged by the consequences of air pollution, and every 10 μg/m³ increase in PM_{10} level increases the mortality rate by 0.2-0.6%.[18,19]

Air pollution deeply affects the respiratory system, cardiovascular, and cerebrovascular systems. On the other hand, PM is known to be a group 1 carcinogen and causes lung and bladder cancer.[20] The 2018 Statistics Yearbook of the Ministry of Health revealed that the diseases which most often lead to death are neoplasms and respiratory system diseases.[21] Our research revealed the persistent air pollution in Turkey which can be closely connected with diseases that lead to death the most such as ischemic heart disease, acute myocardial infarction, cerebrovascular disease, lung cancer, and chronic obstructive pulmonary disease. On the other hand, it has been shown that a decrease in the PM level increases life expectancy. Pope et al.[19] reported that a 10 μg/m³ decrease in $PM_{2.5}$ level increases life expectancy by 0.61 years. In other words, deaths attributable to air pollution are preventable losses.[19] Our research indicates that the air pollution issue has not improved in Turkey between 2016 and 2019, and on the contrary, that it has gained a permanent character in some regions.

The age-standardized premature mortality caused by malignant neoplasms, diabetes, circulatory system diseases, and chronic respiratory diseases is, in 100.000, 390 for men, 190 for women, and 288 in total.[21] The same death rates in Europe are 360, 194, and 273, respectively.[21] The higher numbers of male and total death rates in Turkey compared to Europe can be primarily attributed to tobacco use. However, outdoor air pollution contributes to this difference due to males being in more contact with the outside world.

In a prospective cohort study in Europe where 11 studies were analyzed, for every 10 μg/m³ increase of PM_{10} and $PM_{2.5}$, myocardial infarction increased by 12% and 13%, respectively.[22] Data indicate that pollutant concentrations pose a risk even if they are below European Union (EU) standards.[23] While, as our research has shown, air pollution levels are higher in Turkey compared to the EU. There has not been an improvement in the criteria that PM_{10} level should not be above 50 μg/m³ for more than 35 days in a year. As expected, acute myocardial infarction due to tobacco use

and air pollution is the third most seen cause of death for males in Turkey between 2016 and 2018, after malignant neoplasm and ischemic heart disease.[21]

According to the Air Pollution 2020 Report published by the EU, more than 15% of the urban population in Europe live in places with air pollution as per European standards, and more than 48% live in such places as per the WHO's standards.[24] In Turkey, according to EU and WHO criteria, the rate of populations exposed to air pollution were 19% and 53%, respectively.[25] For Turkey, these ratios were 51%, 79%, and 98% according to standards set by national regulations, the EU, and the WHO, respectively, in 2016. They were updated in the same order as 60%, 60%, and 96% in 2019. In other words, while there was a decrease in terms of European Union limit values in the last 4 years, there was no significant change taking WHO limit values into account. However, since air pollutants do not have a "reliable" limit value, it is more appropriate to accept WHO's limit values to prevent deaths due to air pollution. World Health Organization pays more attention to fine PM pollution in terms of its health effects and, therefore, accepts the annual average limit value for $PM_{2.5}$ as 10 μg/m^3 and the 24-hour average limit value as 25 μg/m^3. Unfortunately, as our study has evidenced, fine PM in Turkey is not traced effectively due to both insufficient measurements of the stations and the lack of a national limit value for $PM_{2.5}$.

The European Environment Agency collects data from more than 7500 air quality monitoring stations across Europe. There are approximately 900 stations in France, 500 in Germany, and 1000 in Spain.[26] Our data show that there were 210 stations between the years 2016 and 2019 in Turkey.[27] On the other hand, the number of air quality monitoring stations in 13 members of the EU and Turkey is only 207 (7%).[28] The number of stations in Turkey was 121 (58.5%) in the same year. In this context, the increasing number of stations in Turkey between 2016 and 2019 has been valuable in both contributing to national air quality and monitoring of air quality in Europe.

In parallel with the increasing number of stations in the 2016-2019 period, the number of stations with insufficient measurements throughout the year is also increasing. According to our research, the number of stations making measurements for 75% of the whole year or less increased from 11% in 2017 to 48% in 2019. In other words, approximately 1 of the 2 stations did not possess adequate air quality data in 2019. These insufficient measurements have eliminated the contribution in terms of monitoring that increasing number of stations in Turkey over the years can make at both national and European levels. On the other hand, it is noteworthy that the stations that do not conduct adequate measurements are in places such as Aliağa, Yatağan, or Göztepe (Istanbul) where there is air pollution caused by heavy industry, thermal power plants, or urban transformation.

Finally, our data draw attention to the population living in provinces and districts with persistent air pollution which is 11 million 265 thousand in total and accounts for 13.7% of the total population of Turkey, indicating a grave risk. Moreover, our data indicate that the stations where the pollution persisted in the last 4 years are mostly those around the industrial zones. This is compatible with the findings that the main factor causing ambient air pollution is provoked by industrialization.[29] However, the data on Turkey's mortality and morbidity and disease burden on a provincial and district level are not available, which hinders the putting forward of the causal relationship between pollution and disease/death.

The most significant limitation of our study is that the number of stations that do not have enough data on air pollution increased with time and that the changing trend of air pollution in Turkey cannot be exhibited accurately. In addition to this limitation which is independent of our research technique, the inability to have the morbidity and mortality data based on the disease burden in specific provinces and districts impedes to demonstrate the relation between disease and death. Finally, very limited observation of $PM_{2.5}$ is also hindering PM pollution in Turkey. However, air pollution is a very serious public health problem and the first step to be taken to fight this problem should be to identify the real magnitude of it and the disease burden created by it. Despite these limitations, our study revealed the measurable size of the air pollution in Turkey which caused fatal problems.

Ethics Committee Approval: Ethical approval is not necessary due to the nature of this study.

Informed Consent: Informed consent is not necessary due to the nature of this study.

Peer Review: Externally peer-reviewed.

Author Contributions: Concept - N.A.; Design - N.A.; Resources - N.A., Y.Y.; Materials - N.A., Y.Y.; Data Collection and/or Processing - N.A.; Analysis and/or Interpretation - N.A., Y.Y.; Literature Review - N.A., Y.Y.; Writing Manuscript - N.A., Y.Y.; Critical Review - N.A., Y.Y.

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