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Original Article

Correlation of COVID-19 Mortality with Socioeconomic Status, Air Quality, and Housing Density

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Abstract

OBJECTIVE: Studies have reported associations between coronavirus disease-2019 (COVID-19) mortality and socioeconomic status (SES) and air pollution, but few have investigated the association with housing density. This ecological study aims to demonstrate the relationship between the COVID-19 mortality rate and these variables in the districts of Ankara.

MATERIAL AND METHODS: COVID-19 mortality rate calculations were based on data from the Ankara Metropolitan Municipality Cemetery Directorate. Air pollution data for the five years preceding the COVID-19 pandemic were obtained from the North Anatolia Clean Air Regional Directorate. The SES values for each district were divided into five categories. Housing density was calculated by dividing the number of households by the area of the district in square kilometers.

RESULTS: Levels of NO_X, O_3, $PM_{2.5}$, and NO (r = 0.78, 0.84, 0.74, and 0.80, respectively) and district-level SES (r = 0.43) were found to be moderately correlated with COVID-19-related deaths. COVID-19-related deaths were positively correlated with housing density (r = 0.68, *P* = 0.001).

CONCLUSION: These variables interact closely and are correlated with COVID-19 mortality across districts of Ankara.

KEYWORDS: Air pollution, socioeconomic status, housing density, COVID-19 mortality, environmental exposure

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INTRODUCTION

Severe acute respiratory syndrome coronavirus 2 is mainly transmitted through close person-to-person contact and by aerosol droplets smaller than 5 μm in diameter. Although nations and governments adopted drastic prevention measures, as of July 23, 2025, the coronavirus disease-2019 (COVID-19) pandemic has caused 7,098,440 deaths and 778,407,760 positive cases.[1,2] Global reports link social factors, in addition to medical ones, to COVID-19 mortality. To our knowledge, this is the first study in Ankara to examine the combined impact of housing density, socioeconomic status (SES), and air pollution indicators on COVID-19 mortality.

Several ecological studies have reported that outdoor air pollution is one of the most significant factors affecting COVID-19 mortality by increasing susceptibility to respiratory tract infections through long-term exposure to air pollution, which induces immunotoxicity, inflammation, and free radical production.[3-6] Similar to exposure to air pollution, socioeconomic inequality affects COVID-19 mortality and should be considered in detail.[6-8] Only a few studies have investigated the effects of housing density on COVID-19 mortality and demonstrated higher mortality in high-density districts.[9,10] This ecological study aims to examine the correlation between COVID-19 mortality and housing density, SES, and air pollution indicators in the districts of Ankara.

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MATERIAL AND METHODS

The study was conducted in accordance with the principles of the Declaration of Helsinki. As this is an ecological study utilizing publicly available aggregated data without any individual-level identifiers, ethical approval was not required in line with national and international research ethics guidelines.

Mortality Data: The COVID-19 mortality data were obtained from the Ankara Metropolitan Municipality Cemetery Directorate because the district-wise numbers of COVID-19-related deaths were not announced by the Turkish Ministry of Health for Ankara. Mortality data were collected from three large central cemeteries where most burials occurred between March 10, 2020, and May 31, 2022. In Türkiye, the code "Natural Death: Contagious Disease" has been added to the ICD-10 classification to determine COVID-19-related deaths.

In our country, the death notification system obligates sending a copy of the death certificate issued by the physician to the cemetery and holds the information on the residential area, age, cause, and date of death.[11] For this study, the number of deaths with the code "Natural Death: Contagious Disease" between March 10, 2020, and May 31, 2022 was obtained from each district's cemetery database and processed accordingly.

Calculation of Housing Density: The population living in the districts of Ankara was determined using the address-based population registration system of TurkStat. First, the number of households was calculated by dividing the population of each district by the average household size, using data from TurkStat's website. Housing was calculated as the number of houses per square kilometer of district area.[12] The housing density of each district is depicted in Figure 1A.

Socioeconomic Status Data: In 2022, the General Directorate of Development Agencies of the Ministry of Industry and Technology published the "Socioeconomic Development of Districts Ranking Study (*Sosyo-Ekonomik Gelişmişlik Endeksi*, SEGE-2022)", which contains information on differences in development among districts in Ankara and represents all dimensions of socioeconomic development.[13] The SEGE index for each district is based on numerical data stratified into five categories, as shown in Figure 1B.

Main Points

- This is the first ecological study in Ankara to jointly evaluate the impacts of air pollution, housing density, and socioeconomic disparities on coronavirus disease-2019 (COVID-19) mortality.
- COVID-19-related deaths in Ankara were significantly correlated with air pollution indicators, particularly long-term exposure to $PM_{2.5}$, NO_X, NO, and O_3.
- Higher housing density was strongly associated with increased COVID-19 mortality across Ankara's districts.
- Contrary to prior international findings, districts with higher socioeconomic status (SES) in Ankara had higher COVID-19 mortality rates.
- COVID-19 mortality was not significantly affected by meteorological variables, but was associated with age and gender, with elderly males accounted for the majority of deaths. This aligns with global evidence emphasizing age and sex as key risk factors for COVID-19 mortality.

Measurements of Air Pollution and National Air Quality Monitoring Network: Ankara is the capital city of Türkiye and has 25 districts, 1,425 neighborhoods, and 18 fixed air quality monitoring stations located in only 9 districts. Neighborhoods covered by these stations and the pollutants measured at each station were obtained from the "Ankara Province Clean Air Action Plan" published by the Ministry of Environment, Urbanization and Climate Change, Ankara Governorship, and Ankara Metropolitan Municipality.[14] The data obtained from the stations, as hourly averages, are transferred to the Data Operation Center of the Laboratory, Measurement and Monitoring Department, which is affiliated with the Ministry of Environment, Urbanization and Climate Change, General Directorate of Environmental Impact Assessment, Permit, and Inspection. At this center, data verification is performed, considering the devices' calibration and alarm information. Accordingly, monthly and annual reports are prepared using verified data, and the raw data obtained from the monitoring network are published simultaneously on www.havaizleme.gov.tr. After data validation is completed, the verified data are transferred to the website at the end of each month. Meteorological variables such as air temperature, humidity, and air pressure are recorded and processed simultaneously.[15,16]

Air pollution data for the five years preceding the COVID-19 pandemic, excluding data from the spring–summer season when reductions in air pollution were expected, were obtained from the North Anatolia Clean Air Regional Directorate. Air pollutants measured at all stations are shown in Table 1. Figures 1C-F show pre-pandemic levels of $PM_{2.5}$, NO_X, NO, and O_3 in the districts. The arithmetic mean of the measured air quality parameters was calculated for each pollutant. Measurements of meteorological variables, namely temperature, humidity, and air pressure, corresponding to the pollutant data, have also been considered in this study.

Statistical Analysis

IBM SPSS Statistics v. 23.0 for Windows was used for statistical analysis. District-level correlations between the COVID-19 mortality rate and air pollutants, housing density, and SES score were assessed using the Pearson correlation test. Cross-tabulation analysis was used to assess the relationships among multiple variables. A P value smaller than 0.05 was considered statistically significant.

RESULTS

Burials from four districts —Kalecik, Güdül, Pursaklar, and Evren— located in the three central cemeteries were not taken into consideration due to their location. More than 75% of the patients who died due to COVID-19 were older than 65 years of age. In addition, approximately 60% of elderly individuals were male, accounting for nearly the same proportion of total COVID-19-related deaths.

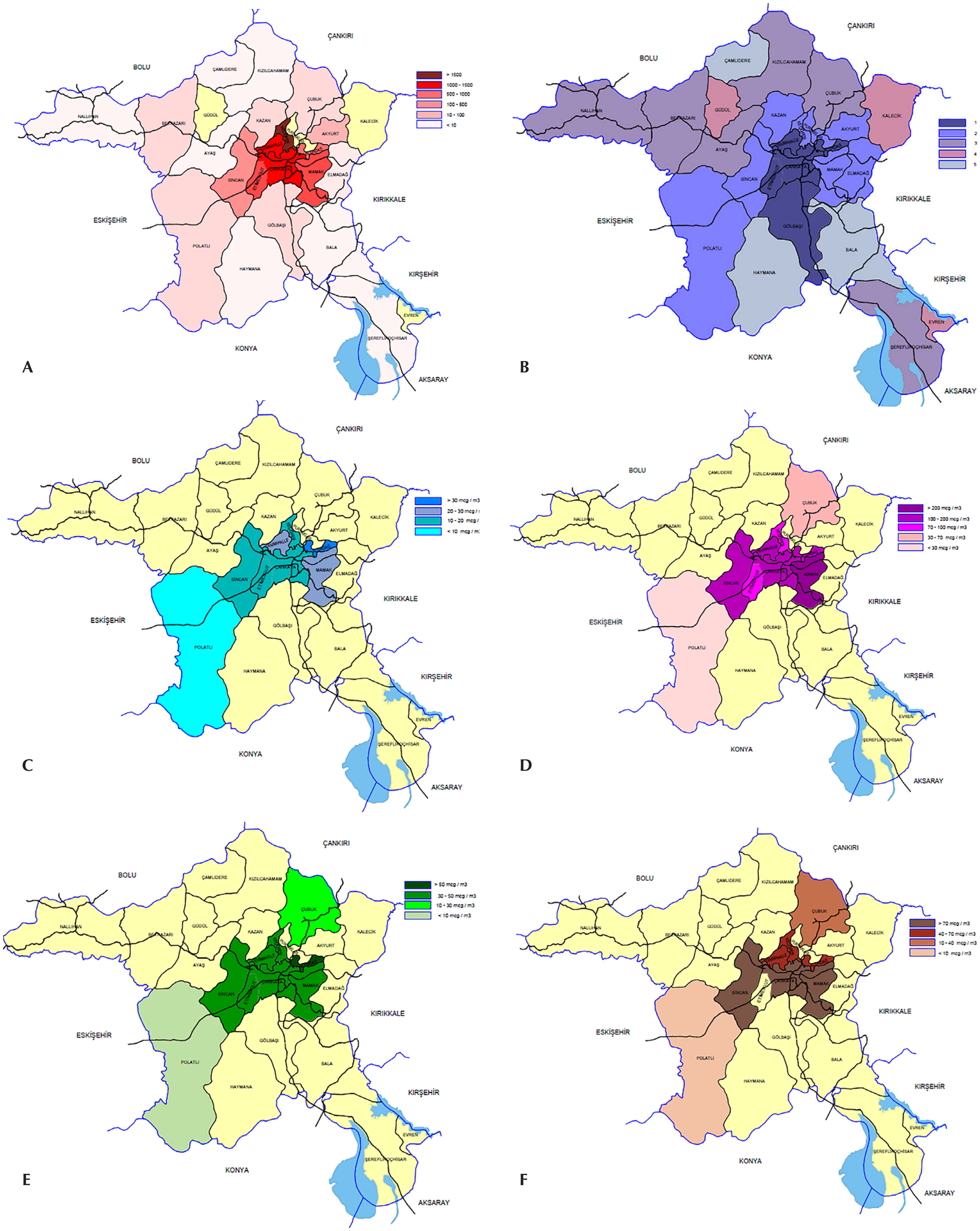

Figure 1. Spatial distribution of key variables analyzed in the study
A) Housing density (households/km[2]) by district in Ankara, calculated using TurkStat address-based population registration system data (2022)
B) Socioeconomic status index (*Sosyo-Ekonomik Gelişmişlik Endeksi*, SEGE-2022), stratified into 5 categories by the General Directorate of Development Agencies, Ministry of Industry and Technology
C) Mean pre-pandemic levels of $PM_{2.5}$ (μg/m³) across districts, based on validated data from the National Air Quality Monitoring Network (2015-2019)
D) Mean pre-pandemic levels of NO_X (μg/m³) across districts, measured by fixed monitoring stations in 9 districts and averaged over 2015-2019
E) Mean pre-pandemic levels of NO (μg/m³) across districts, obtained from the same monitoring network (2015-2019)
F) Mean pre-pandemic levels of O_3 (μg/m³) across districts, reported by the Ministry of Environment, Urbanization and Climate Change
All variables shown were subsequently analyzed in relation to district-level COVID-19 mortality (March 2020-May 2022)
COVID-19: Coronavirus disease-2019

The percentage of the population and the COVID-19 mortality rates for each district of Ankara are presented in Table 2. The population is mainly concentrated in seven districts where air quality measurements are conducted, while the remaining districts hold less than 5% of the population, resulting in a heterogeneous distribution.

Table 3 demonstrates the correlations between COVID-19-related deaths and the variables considered in this study. Total COVID-19-related deaths were positively correlated with housing density and SES indices (r = 0.68, *P* = 0.001, and r = 0.48, *P* = 0.03, respectively). In Table 4, the correlations between the variables and COVID-19-related deaths among people aged 65 years and older are presented. Regarding pollutants, levels of $PM_{2.5}$, NO_X, O_3, and NO were correlated with total COVID-19-related deaths; in contrast, for deaths among the elderly only O_3 levels were correlated (r = 0.77, *P* = 0.02) (Tables 3 and 4). Total COVID-19-related deaths were not correlated with meteorological variables. Although the average household size was not correlated with the total COVID-19 death rate, it was correlated with COVID-19–related deaths among the elderly (Tables 3 and 4). Additionally, Table 5 illustrates the relationship between the study variables and COVID-19 mortality rates in males and females older than 65 years.

Table 1. List of air quality monitoring stations and measured pollutants in each district

Name of the district	Measured parameter
Çankaya	
Bahçelievler	PM_{10}, $PM_{2.5}$, NO_X, NO_2, NO, CO, SO_2
Çankaya	PM_{10}, $PM_{2.5}$, NO_X, NO_2, NO, CO, SO_2, O_3
Sıhhiye	PM_{10}, $PM_{2.5}$, NO_X, NO_2, NO, CO, SO_2, O_3
Yaşamkent	PM_{10}, $PM_{2.5}$, NO_X, NO_2, NO, CO, SO_2, O_3
Yenimahalle	
Batıkent	PM_{10}, NO_X, NO_2, NO, SO_2, O_3
Demetevler	PM_{10}, $PM_{2.5}$, NO_X, NO_2, NO, SO_2
Ostim	PM_{10}, $PM_{2.5}$, NO_X, NO_2, NO, CO, SO_2, O_3
Çubuk	NO_X, NO_2, NO, SO_2, O_3
Etimesgut	PM_{10}, $PM_{2.5}$, NO_X, NO_2, NO, CO, SO_2
Mamak	PM_{10}, NO_X, NO_2, NO, CO, SO_2, O_3
Kayaş	PM_{10}, SO_2
Keçiören	PM_{10}, $PM_{2.5}$, NO_X, NO_2, NO, SO_2, O_3
Etlik	PM_{10}, NO_X, NO_2, NO, CO, SO_2
Polatlı	PM_{10}, NO_X, NO_2, NO, CO, SO_2, O_3
Sincan	PM_{10}, $PM_{2.5}$, NO_X, NO_2, NO, SO_2
Törekent	PM_{10}, $PM_{2.5}$, NO_X, NO_2, NO, SO_2, CO
Altındağ	
Siteler	PM_{10}, $PM_{2.5}$, NO_X, NO_2, NO, CO, SO_2, O_3
Ulus	PM_{10}, $PM_{2.5}$, NO_X, NO_2, NO, CO, SO_2, O_3

Table 2. COVID-19 mortality rates of districts

District	Population (% in the province)	COVID-19 mortality rate (per 10,000)	COVID-19 mortality rate of elderly (per 10,000)	COVID-19 mortality rate of males (per 10,000)	COVID-19 mortality rate of females (per 10,000)
With air quality measurement station					
Çankaya	16.52	13.03	19.10	16.57	9.77
Keçiören	16.41	12.62	31.71	14.96	10.37
Yenimahalle	12.25	14.09	31.15	18.11	10.29
Mamak	11.87	14.78	38.79	20.94	8.67
Etimesgut	10.55	6.89	55.98	9.32	4.47
Sincan	9.77	12.18	62.84	13.72	10.57

Table 2. Continued

District	Population (% in the province)	COVID-19 mortality rate (per 10,000)	COVID-19 mortality rate of elderly (per 10,000)	COVID-19 mortality rate of males (per 10,000)	COVID-19 mortality rate of females (per 10,000)
Altındağ	7.09	11.97	18.52	11.95	11.98
Polatlı	2.22	4.7	6.95	5.33	4.07
Çubuk	1.59	9.52	14.49	10.30	8.74
Without air quality measurement station					
Gölbaşı	2.49	1.89	6.22	1.39	0.97
Kahramankazan	1.01	3.62	6.36	4.72	2.47
Beypazarı	0.84	3.72	2.71	3.31	4.11
Elmadağ	0.77	7.68	9.90	6.74	8.63
Akyurt	0.67	6.99	18.92	7.10	6.88
Şereflikoçhisar	0.58	5.07	3.10	4.16	5.99
Haymana	0.47	6.96	4.40	7.02	6.88
Kızılcahamam	0.47	6.3	3.21	2.91	9.83
Nallıhan	0.47	2.59	0.88	2.98	2.21
Bala	0.40	5.66	3.86	5.55	5.78
Ayaş	0.23	9.16	4.13	9.95	8.24
Çamlıdere	0.15	8.38	3.67	6.78	10.18

COVID-19: Coronavirus disease-2019

Table 3. Correlations of COVID-19 mortality rate with the variables

	n	%	Correlation coefficient	*P*
NO	5975	93	**0.80**	**0.01***
NO_2	5975	93	0.43	0.25
NO_X	5975	93	**0.78**	**0.01***
PM_{10}	6078	95	0.53	0.18
$PM_{2.5}$	5888	**92**	**0.74**	**0.04***
SO_2	6105	96	0.58	0.14
O_3	3913	**61**	**0.84**	**0.01***
CO	2750	43	0.53	0.23
Temperature	6165	97	0.11	0.77
Humidity (%)	6165	97	0.14	0.72
Pressure	6165	97	-0.31	0.40
SES index	6384	100	**0.48**	**0.03***
Average household size	6384	100	0.17	0.45
Housing density	6384	100	**0.68**	**0.001***

*$P < 0.05$ was considered statistically significant, COVID-19: Coronavirus disease-2019, SES: Socioeconomic status

Table 4. Correlation of air pollutant types with the COVID-19 mortality rate in the elderly (>65 years old)

	n	%	Correlation coefficient	*P*
NO	4584	72	0.32	0.38
NO_2	4584	72	0.23	0.54
NO_X	4584	72	0.39	0.29
PM_{10}	4610	72	0.30	0.46
$PM_{2.5}$	4519	71	0.11	0.78
SO_2	4691	73	0.06	0.87
O_3	3013	**47**	**0.77**	**0.02***
CO	2132	33	-0.19	0.68
Temperature	4735	74	0.15	0.68
Humidity (%)	4735	74	-0.24	0.53
Pressure	4735	74	0.09	0.81
SES index	4880	**76**	0.35	0.10
Average household size	4880	76	**0.50**	**0.02***
Housing density	4880	76	**0.49**	**0.02***

*$P < 0.05$ was considered statistically significant, COVID-19: Coronavirus disease-2019, SES: Socioeconomic status

Table 5. Correlation of air pollutants with COVID-19 mortality rates in male and female patients (>65 years old)

	Male			Female		
	n	Correlation coefficient	*P*	n	Correlation coefficient	*P*
NO	3654	**0.70**	**0.03***	2321	**0.76**	**0.02***
NO_2	3654	0.39	0.30	2321	0.38	0.30
NO_X	3654	**0.84**	**0.004***	2321	0.43	0.24
PM_{10}	3731	0.51	0.19	2347	0.41	0.31
$PM_{2.5}$	3607	0.61	0.10	2281	**0.76**	**0.03***
SO_2	3744	0.48	0.22	2361	0.56	0.14
O_3	2397	**0.82**	**0.01***	1516	0.60	0.11
CO	1658	0.40	0.36	1092	0.61	0.14
Temperature	3778	-0.09	0.80	2387	0.43	0.24
Humidity (%)	3778	0.28	0.45	2387	-0.12	0.74
Pressure	3778	-0.28	0.45	2387	-0.31	0.41
SES index	3891	0.55	0.01	2493	0.24	0.29
Average household size	3891	0.27	0.23	2493	-0.06	0.76
Housing density	3891	**0.72**	**0.001***	2493	**0.46**	**0.03***

*$P < 0.05$ was considered statistically significant, COVID-19: Coronavirus disease-2019, SES: Socioeconomic status

DISCUSSION

Ankara, located in central Anatolia, is the second-most populous city in Türkiye, with a population of 5,747,325, according to Turkish Statistical Institute 2021 data. By surface area (km^2), it is the third-largest city in Türkiye, after Konya and Sivas. The province has a population density of 224 people per km^2, and the district with the highest density is Keçiören, with 5,930 people per km^2.[12] Approximately three-quarters of the population are employed in the service sector, which includes civil service, transportation, communication, and trade; one-quarter are employed in industry, and 2% are employed in agriculture. The industry is concentrated mainly in the textile, furniture, foundry, defense, and construction, which are located in 12 organized industrial zones covering a total area of more than 60 million square meters.[17] The traffic burden is considerable, particularly in central districts. Air pollution in Ankara reached dangerous levels in the early 1980s. However, currently, moderate air pollution exists due to the widespread use of natural gas instead of low-quality coal.[14]

Harmful effects of air pollutants on the respiratory tract have been investigated extensively, and many studies have revealed a correlation between air pollution and COVID-19-related deaths.[4-6,18-20] In a meta-analysis, Zang et al.[21] reported that both short- and long-term exposure to air pollutants were correlated with COVID-19 incidence and mortality. To reduce the adverse effects of outdoor air pollution during pandemics, epidemiological research should be conducted, and appropriate precautions should be implemented promptly.[21] In our study, we observed a significant correlation between COVID-19-related deaths and particularly high concentrations of NO_2, O_3, and $PM_{2.5}$. However, a major limitation of this study was the insufficient number of air-quality monitoring stations, which were located in only nine densely populated districts. This limitation prevented our research from providing a comprehensive assessment of air quality across the city, thereby reducing the representativeness of the data. Future research would benefit from an expanded network of monitoring stations covering a broader range of districts within the city. By drawing attention to the inadequacy of monitoring stations in the capital, we aim to encourage the expansion and strategic placement of additional stations, contribute to public health efforts, and support the development of more effective policies to address air pollution and its potential impact on COVID-19 outcomes. These improvements would allow a more accurate assessment of air pollution levels, better-informed decision-making, and targeted interventions to mitigate health risks, ultimately encouraging authorities to allocate resources to strengthen the city's air quality monitoring infrastructure.

The importance of social determinants of health has become more apparent during the COVID-19 pandemic. Many studies have indicated that COVID-19 is more severe and that the number of deaths is higher in regions where the inhabitants have low SES.[22-25] A systematic review and meta-analysis found a strong correlation between SES and COVID-19 outcomes.[26]

In this study, we observed a higher COVID-19 mortality rate in districts with high SES, which contrasts with findings from other studies.[27-29] This discrepancy is attributable to factors such as population crowding and an older population in those districts, as supported by data from TurkStat and the SEGE 2022 study.[12-14] These unique characteristics of the population in high-SES districts contributed to higher vulnerability to COVID-19 and ultimately higher mortality rates. Additionally, alternative explanations should be considered. Residents of socioeconomically disadvantaged districts often face obstacles in accessing healthcare services and may experience delays in diagnosis or treatment.[30,31] Limited diagnostic resources in hospitals serving disadvantaged areas and well-documented underreporting of deaths due to documentation problems can also contribute to artificially low mortality figures.[32,33] Thus, the inverse association observed in our study may partly reflect disparities in access to care and reporting practices rather than true differences in mortality burden.

It is also possible that deaths in central, densely populated districts were more consistently documented due to easier hospital access, whereas deaths in rural or peripheral districts might have occurred at home and remained undocumented. This potential reporting bias should be acknowledged when interpreting the results.

Furthermore, sourcing data on COVID-19-related deaths exclusively from three central cemeteries is a significant limitation of our study. The limited scope of data collection from central cemeteries prevents a comprehensive understanding of COVID-19 mortality rates in smaller districts. Access to information on COVID-19-related deaths in smaller districts would provide a more accurate and complete assessment of the impact of the virus across different areas of the city. It is essential to acknowledge these limitations and consider them when interpreting the results of the study. Our future research efforts could aim to address these limitations by expanding data collection to include smaller districts and implementing more comprehensive sampling strategies to capture a broader representation of the population.

Housing density reflects the number of households per km^2. The effect of housing density on the COVID-19 mortality rate has also been reported in various studies, supporting our findings;[34-36] yet Wang et al.[37] observed a dose-response relationship between these parameters. In our study, however, the association was positive but not dose-dependent. This discrepancy may be explained by differences in study design (ecological vs. longitudinal), population structure, and the level of detail in the available housing and environmental data. Nevertheless, our results are consistent with the broader conclusion of Wang et al.[37] that high housing density increases the risk of COVID-19 mortality. These studies demonstrate that areas with higher housing density are associated with an increased risk of COVID-19 transmission and mortality. The close proximity and shared spaces in densely populated housing contribute to higher infection rates and poorer health outcomes. Our study contributes to the evidence that housing density is a significant factor in understanding and addressing COVID-19 mortality rates. Further investigations into the influence of housing density on COVID-19 outcomes would provide valuable guidance for public health interventions and policymaking.

Study Limitations

Despite the aforementioned limitations, this study stands out as the first to demonstrate this relationship specifically in the densely populated districts of Ankara. In the near future, as the Ministry of Health provides updated statistics on the distribution of COVID-19-related deaths, it will become possible to conduct further studies encompassing all the provinces of Ankara. These future studies could yield additional valuable insights into the impact of social disparities, air pollution, and housing density on COVID-19 outcomes.

CONCLUSION

This ecological study identified notable associations between air pollution, housing density, and COVID-19-related mortality across the districts of Ankara. Higher mortality rates were observed in areas with greater SES, likely reflecting demographic characteristics such as older age and higher population density. These findings call for improved air quality monitoring and public health strategies that consider both environmental and social determinants of health. While limited by data availability and uneven distribution of monitoring stations, this study provides an important foundation for future research aimed at guiding more effective and equitable health policies.

Ethics

Ethics Committee Approval: Not applicable.

Informed Consent: Informed consent was not required fort his ecological study.

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Footnotes

Authorship Contributions

Surgical and Medical Practices: E.R.Ş., Ö.G., A.U.D., A.F.K., Concept: E.R.Ş., A.U.D., A.F.K., Design: E.R.Ş., A.U.D., A.F.K., Data Collection or Processing: E.R.Ş., Ö.G., A.U.D., A.F.K., Analysis or Interpretation: Ö.G., A.U.D., A.F.K., Literature Search: E.R.Ş., Ö.G., A.U.D., A.F.K., Writing: E.R.Ş., Ö.G., A.U.D., A.F.K.

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