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Original Article

The Causal Link Between Air Pollution and Respiratory Diseases: Evidence from Granger Causality Test

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Abstract

OBJECTIVE: Air pollution can exacerbate respiratory illnesses, such as asthma, chronic obstructive pulmonary disease (COPD), pneumonia, bronchitis, and upper respiratory tract infections (URTIs). This study investigated the causal relationship between air pollution and emergency department visits for certain respiratory illnesses, such as pneumonia, acute bronchitis, URTIs, and exacerbations of asthma and COPD.

MATERIAL AND METHODS: This study was conducted between 1 April 1 2023 and 30 March 2024. The causal relationship between the number of asthma, COPD, pneumonia, bronchitis, and URTI patients visiting the emergency department and air pollution levels was determined by conducting a Granger causality analysis.

RESULTS: It was determined that the highest number of visits to the emergency room was in January, and the highest concentrations of air pollutants were in December. According to the results of the Granger causality test, there was a one-way causal relationship between nitrogen (NO), nitrogen oxide (NO_X), and nitrogen dioxide (NO_2) levels and the numbers of patients with asthma, COPD, pneumonia, bronchitis, and URTI, as well as a relationship between particulate $matter_{10}$ (PM_{10}) concentrations and the numbers of patients with pneumonia and bronchitis.

CONCLUSION: There is a causal relationship between levels of air pollutants including NO, NO_X, NO_2, and PM_{10} and the numbers of patients with respiratory diseases visiting the emergency department.

Keywords: Respiratory diseases, Granger causality, air pollutants, human exposure assessment

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INTRODUCTION

Air pollution is defined by the World Health Organization (WHO) as the pollution of the indoor or outdoor environment by any chemical, physical, or biological agent that alters the natural properties of the atmosphere.[1] The health effects of air pollution remain a public health concern worldwide. Exposure to air pollution has many substantial adverse effects on human health. Air pollution can induce the acute exacerbation of chronic obstructive pulmonary disease (COPD) and the onset of asthma, increasing respiratory morbidity and mortality rates. The health effects of air pollution depend on the components and sources of pollutants, which vary depending on countries, seasons, and time.[2] According to the WHO 2021 report, 99% of people breathe polluted air, and approximately 7 million deaths are caused by air pollution and related complications.[3] Air pollution ranks 4th globally and 5th in Türkiye among the risks factors of deaths.[4,5] Air pollution has severe health impacts, and it was reported that one-third of deaths from diseases such as stroke, lung cancer, and heart disease were associated with air pollution.[1]

Domestic fuels, motor vehicles, industrial facilities, and wildfires are familiar sources of air pollution. Gaseous pollutants that cause air pollution and health problems include carbon monoxide (CO), ozone (O_3), NO_2, and sulfur dioxide (SO_2).[1] Particulate matter (PM) consists of micrometric substances suspended in the air and is mainly produced by industrial processes, coal-oil burning, road construction, and agricultural activities. Particles smaller than 10 microns are called PM_{10}, and those smaller than 2.5 microns are called $PM_{2.5}$. These PM categories are frequently used in air pollution

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studies. Inhaled into the respiratory tract, PM larger than 10 microns is retained in the nose and nasopharynx, particles smaller than 10 microns are deposited in the bronchi, particles 1-2 microns in diameter are collected in the alveoli, and particles 0.5 microns in diameter diffuse from the alveoli into the intracapillaries.[6] While SO_2, one of the gaseous pollutants of air, is eliminated in the nose and pharynx, O_3 and NO_2, which are not water-soluble gases, can reach deep into the respiratory system. CO diffuses through the alveolar-capillary membrane and binds to hemoglobin.[6] Studies conducted in Türkiye have reported a significant relationship between pollutants such as SO_2 and PM_{10} and respiratory diseases.[7-9]

In Türkiye, air quality is one of the primary concerns about environmental pollution, especially in areas with intense industrialization. People are exposed to PM emitted from vehicles at dangerous levels, and the concentrations of these pollutants are above WHO's standards. The transportation sector, the second sector after the industrial sector in terms of energy use in Türkiye, is the primary source of air pollution.[10] Tuygun et al.[10] (2017) reported that industrial facilities in the industrial zone cause SO_2, nitrogen oxide (NO_X), and PM_{10} emissions, while residential heating and road traffic cause an increase in CO emissions.[11] The presence of brick factories, tobacco and vine leaf cultivation, and denim and dye factories in Erbaa, through which a highway with intensive truck transportation passes, changes the air pollution rate of the district. In the literature, a relationship between air pollutants and respiratory diseases has been reported, but there have not been many studies examining emergency room visits due to air pollution and respiratory diseases together. Additionally, causality in the relationship between these two factors has not been investigated in existing studies.[12,13]

In health research, causality is defined as the occurrence of one event or situation due to another event or situation.[14] The Granger causality test is generally used to determine a causality relationship. Since causality tests are econometric tests, these tests are used mainly in economics and econometrics. However, today, this test is widely used in natural sciences, engineering, and health sciences.[15-17] By definition, a random variable X is said to be a Granger cause of Y if its history, after considering all other possible relevant factors and non-random information, provides a better prediction of the future of another random variable Y.[15] Determining whether there is a relationship between air pollutants and the number of patients presenting to emergency care for asthma, COPD, pneumonia, bronchitis, and upper respiratory tract infections (URTI) would be beneficial in managing diseases, creating care plans, and adjusting healthcare system budgets. Programs can be created by considering this causality relationship in educational practices, which are among the roles of nurses. The self-management skills of patients can be improved by considering the effects of outdoor air pollution on diseases.

This study aimed to show the causal relationship between the air quality, in relation to air pollution, and the number of visits to the emergency department at Erbaa State Hospital due to respiratory diseases including pneumonia, acute bronchitis, URTI, and exacerbations of asthma and COPD.

Main Points

- Exposure to air pollution: the air pollutants PM_{10}, NO_X, and NO levels were highest in December 2023, SO_2 was highest in February 2024, and NO_2 was highest in April 2023.
- Impact of exposure to air pollution: Hospital admissions are higher following months when air pollution is high compared to other months. Relationship of air pollution and admission emergency: increases in air pollutants such as NO, NO_X, NO_2, and PM_{10} effectively determine the number of patients admitted to the emergency department.
- Need for targeted interventions: the findings emphasize the necessity for enhanced enforcement of policies and targeted public health interventions to reduce air pollution.

MATERIAL AND METHODS

This study was conducted with a retrospective design to examine the causal relationship between the daily air pollutant levels published by the Turkish Ministry of Environment and Urbanization and the number of respiratory system patients visiting the emergency department.

In this study, the data of patients with asthma, COPD, pneumonia, bronchiectasis, and URTI visiting the emergency department at Erbaa State Hospital between 1 April 2023 and 30 March 2024 were examined retrospectively.

The inclusion criteria were determined according to the International Classification of Diseases, revision 10 (for codes: J45.9-asthma; J44.0, J44.1, J44.9-COPD; J18.9-pneumonia; J20.9-acute bronchitis; J42-chronic bronchitis, and J06.8, J06.9-URTI), and data about patients diagnosed with asthma, COPD, bronchitis, pneumonia, and URTI were included. Respiratory diseases defined by other codes in the same classification system were not included in the study. Twelve months of data were collected, and the months were divided into two main groups: warm months (April, May, June, July, August, and September) and cold months (October, November, December, January, February, and March).

Data Collection

Health data: Data were collected from retrospective patient records. The data consisted of the numbers of patients diagnosed with asthma, bronchitis, pneumonia, URTI, and COPD presenting to the emergency department. Data collection started after obtaining the necessary permissions from the Erbaa Provincial Directorate of Health and informing the health professionals in the Statistics/Information Processing Units of the relevant hospital.

Air pollution data: SO_2, NO, NO_X, NO_2, CO, PM_{10}, and $PM_{2.5}$ were selected as air pollution indicators. Daily data on indicators were obtained from the air quality monitoring website of the Turkish Ministry of Environment and Urbanization. Data on 24-hour average SO_2, NO, NO_X, NO_2, CO, PM_{10}, and $PM_{2.5}$ concentrations for the days when the patients whose data we examined visited were recorded based on the website (mobil.

airizleme.gov.tr) in units of µg/m^3. $PM_{2.5}$ and CO data for the Erbaa/Tokat region were unavailable on the website, and analyses related to these values could not be performed.

Ethical statements

Approval was obtained from Tokat Gaziosmanpaşa University Ethics Committee for conducting the study (date/number: 21.05.2024/09.12).

Statistical Analysis

The Statistical Package for the Social Sciences (SPSS) for Windows 20 (IBM SPSS Inc., Chicago, IL) program was used for the statistical analyses. The categorical variables are expressed as frequencies and percentages. The differences between groups of variables were analyzed using t-tests. The relationships between variables were tested by regression analysis. Granger causality analysis was performed using the Stata 15.0 program. A value of $P < 0.05$ was considered significant in the statistical analyses. In the Granger causality test, the significance level was accepted as 10%. Detailed information about the Granger causality test is presented in the additional file.

RESULTS

The results of this study, which was conducted to demonstrate the causal relationship between air pollution and the numbers of respiratory disease patients visiting the emergency department of a state hospital in the Black Sea Region of Türkiye in the last year, are presented in this section.

The numbers of patients visiting the emergency department for one year and air pollution statistics in the same period are shown in Table 1. As seen in Table 1, the total number of patients with respiratory diseases who presented to the emergency department was 727,915. The highest number of visits was due to URTI at 296,027, asthma at 21,907, and bronchitis at 14,739. The highest number of emergency room visits for respiratory system diseases occurred in January 2024. The levels of PM_{10}, NO_X, and NO were the highest in December 2023, the levels of SO_2 were the highest in February 2024, and the levels of NO_2 were the highest in April 2023 (Table 1).

The results of the analyses performed to test whether there was a significant difference between the numbers of patients visiting the emergency department due to respiratory system diseases in warm and cold months are presented in Table 2. It was determined that the numbers of emergency department visits in cold months were higher for all respiratory diseases examined in this study, while this increase was statistically significant in patients diagnosed with pneumonia, in those with bronchitis, and in overall cases ($P < 0.05$) but not statistically significant in asthma, COPD, and URTI cases ($P > 0.05$) (Table 2).

The results of the analyses conducted to determine whether there was a significant difference between the air pollutant rates in the warm and cold months during the study period are presented in Table 3. As seen in Table 3, in cold months, NO, SO_2 and PM_{10} values reached about five times, more than two times, and almost two times their values in warm months, respectively. These increases were statistically significant ($P < 0.05$). NO_2 and NO_X values also increased in cold months compared to warm months, but this increase was not statistically significant ($P > 0.05$) (Table 3).

The Granger causality test was used to determine the direction of causality and which variable was causally determinant for another variable.[18] The results of the Granger causality test conducted to determine the causal relationship between the numbers of patients with respiratory diseases visiting the emergency department and the levels of air pollutants are presented in Table 4. Accordingly, the null hypothesis was rejected for the causal relationship between NO, NO_2, and NO_X and the number of asthmatic patients since the probability value

Table 1. Number of respiratory disease patients visiting emergency rooms and air pollutant concentrations by months

Months	Respiratory diseases						Air pollutants				
	Asthma	COPD	Pneumonia	URTI	Bronchitis	Total	PM_{10}	SO_2	NO_2	NO_X	NO
April 2023	1,672	677	567	29,331	935	56,722	27.39	4.07	**79.50**	85.69	6.19
May 2023	1,994	907	610	23,423	1,078	59,756	26.78	4.36	57.64	60.62	3.01
June 2023	1,783	845	***410***	20,684	892	53,915	25.01	4.32	35.38	38.25	2.86
July 2023	1,549	794	520	21,208	***825***	61,900	32.71	4.93	26.11	29.13	3.01
August 2023	***1,249***	624	429	***15,883***	***825***	59,687	49.78	3.17	15.26	17.98	2.71
September 2023	1,464	***610***	443	18,845	936	***51,709***	49.14	5.28	14.86	18.71	3.85
October 2023	1,720	760	581	25,164	1,357	59,118	67.12	6.95	27.94	38.09	10.15
November 2023	1,617	716	587	23,134	1,509	57,420	53.12	8.35	36.08	45.63	9.48
December 2023	1,980	687	696	34,642	1,718	68,183	**86.79**	8.74	67.97	**95.20**	**27.23**
January 2024	**2,742**	**1,051**	**997**	**38,876**	**2,040**	**73,184**	57.35	11.16	31.08	44.52	13.39
February 2024	2,238	963	701	20,392	1,307	63,173	63.06	**11.98**	37.09	50.22	13.11
March 2024	1,899	833	667	24,445	1,317	63,148	49.54	9.25	36.68	53.45	16.78
Total	**21,907**	9,467	7,208	**296,027**	**14,739**	**727,915**					

URTI: upper respiratory tract infections, NO: nitrogen, NO_X: nitrogen oxide, NO_2: nitrogen dioxide, PM_{10}: particulate matter$_{10}$, SO_2: sulfur dioxide was smaller than 5% (0.0141, 0.0346, and 0.0272 <0.05). In the analysis of the causal relationship between PM_{10} and SO_2 and the number of asthmatic patients, the null hypothesis could not be rejected because the probability was greater than 5% (0.3334 and 0.1080 >0.05). Accordingly, a unidirectional Granger causality relationship was detected from NO, NO_2, and NO_X to the number of patients with asthma. According to these results, NO, NO_2, and NO_X were Granger causes of asthma, while PM_{10} and SO_2 were not Granger causes of asthma.

In the analyses of the causal relationships between NO, NO_2, and NO_X and the number of patients with COPD, the null hypothesis was rejected because the probability value was smaller than 10% (0.0930 <0.10, 0.0635 <0.10, and 0.0224 <0.05). In the analyses of the causal relationships between PM_{10} and SO_2 and the number of patients with COPD, the null hypothesis could not be rejected because the probability was higher than 5% (0.6737 and 0.4143 >0.05). Accordingly, a unidirectional Granger causality relationship was detected from levels of NO, NO_2, and NO_X to the number of patients with COPD. According to these results, NO, NO_2, and NO_X were Granger causes of COPD, while PM_{10} and SO_2 were not Granger causes of COPD.

In the analyses of the causal relationships between NO, NO_2, NO_X, and PM_{10} and the number of patients with pneumonia, the null hypothesis was rejected since the probability value was smaller 10% (0.0462, 0.0421, 0.0292 <0.05, and 0.0957 <0.10). In the analysis of the causal relationship between SO_2 and the number of patients with pneumonia, the null hypothesis could not be rejected since the probability was greater than 5% (0.2360 >0.05). Accordingly, a unidirectional Granger causality relationship was found between NO, NO_2, NOx, and PM_{10} levels and the number of patients with pneumonia. According to these results, NO, NO_2, NO_X, and PM_{10} were Granger causes of pneumonia, while SO_2 was not a Granger cause of pneumonia.

In the analyses of the causal relationships between NO, NO_2, and NO_X levels and the number of patients with URTI, the null hypothesis was rejected because the probability value was smaller than 10% (0.0773, 0.0632, and 0.0626 <0.10). In the analyses of the causal relationships between PM_{10} and SO_2 levels and the number of patients with URTI, the null hypothesis could not be rejected because the probability value was greater than 5% (0.3089 and 0.3033 >0.05). Accordingly, a unidirectional Granger causality relationship was detected from NO, NO_X, and NO_2 to the number of patients with URTI. According to these results, NO, NO_2, and NO_X were causes of URTI, while PM_{10} and SO_2 were not causes of URTI.

In the analyses of the causal relationships between NO, NO_2, NO_X, and PM_{10} levels and the number of patients with bronchitis, the null hypothesis was rejected since the probability value was smaller than 10% (0.0011 and 0.0028 <0.05, 0.0616, and 0.0852 <0.10). The null hypothesis could not be rejected in the analysis of the causal relationship between SO_2 levels and the number of patients with bronchitis patients since the probability value was higher than 5% (0.6319 >0.05). Accordingly, a unidirectional Granger causality relationship was detected from NO, NO_2, and PM_{10} to the number of patients with bronchitis. According to these results, NO, NO_2, NO_X, and PM_{10} were causes of bronchitis, while SO_2 was not a cause of bronchitis (Table 4).

A multiple regression model was established with all four predictor variables, and the final model was created by excluding those that did not contribute statistically significantly to the model. It was determined that every unit increase in SO_2 values corresponded to 99 asthma (*P* = 0.005), 49 COPD (*P*

Table 2. Number of patients visiting emergency services in warm and cold months

Number of patients admitted to the emergency department (mean±SD)	Warm months	Colder months	Test value
Asthma	1618.50±259.289	2032.67±409.022	t=-2.095, *P* = 0.063
COPD	742.83±123.375	835.00±144.730	t=-1.187, *P* = 0.263
Pneumonia	496.50±81.616	704.83±152.384	t=-2.952, ***P* = 0.014**
URTI	21,562.33±4,568.370	27775.50±7271.062	t=-1.772, *P* = 0.107
Bronchitis	915.17±93.956	1541.33±289.876	t=-5033, ***P* = 0.001**
Total	57,281.5000±3,897.1590	64037.6667±5837.37937	t=-2.358, ***P* = 0.040**

SD: standard deviation, COPD: chronic obstructive pulmonary disease, URTI: upper respiratory tract infections

Table 3. Levels of air pollutants in warm and cold months

Air pollutant values (mean±SD)	Warm months	Cold months	Test value
PM_{10}	35.134±11.39	62.829±13.36	t=-3.862, ***P* = 0.003**
SO_2	4.354±0.72	9.404±1.86	t=-6.191, ***P* < 0.001**
NO_2	38.124±25.72	39.473±14.42	t=-0.112, *P* = 0.913
NO_X	41.731±26.66	54.521±20.609	t=-0.930, *P* = 0.374
NO	3.604±1.32	15.023±6.52	t=-4.199, ***P* = 0.002**

SD: standard deviation, NO: nitrogen, NO_X: nitrogen oxide, NO_2: nitrogen dioxide, PM_{10}: particulate matter$_{10}$, SO_2: sulfur dioxide

= 0.002), 43 pneumonia (*P* = 0.002), and 106 bronchitis (*P* = 0.001) patients visiting the emergency department. It was also determined that every unit increase in PM_{10} values predicted 5 COPD patients (*P* = 0.016), and every unit increase in NO values predicted 570 URTI (*P* = 0.025) patients visiting the emergency department (Table 5).

DISCUSSION

Respiratory tract diseases are important as they rank third in the list of diseases that cause death in the world and Türkiye.[19,20] Since the incidence of respiratory diseases is gradually increasing worldwide, causing an increase in mortality and morbidity rates, it is important to examine the relationship between air pollution and the number of patients visiting hospitals. The results of this study showed that the highest number of visits to the emergency department by patients with respiratory diseases was in January. The number of patients visiting the emergency department increased in the cold months, and this increase was statistically significant for diseases such as pneumonia and bronchitis. The air pollutants, PM_{10}, NO_X, and NO, had the highest levels in December 2023, whereas SO_2 had the highest levels in February 2024, and NO_2 had the highest levels in April 2023. These results were likely because individuals exposed to high concentrations of air pollutants in December presented to the emergency room the following month of January. The results of the Granger causality test also supported this conclusion.

In this study, air pollutant levels differed between warm and cold months. In the cold months, NO, SO_2, and PM_{10} values reached about five times, more than two times, and almost two times, respectively, their levels in the warm months, and these increases were found to be statistically significant. NO levels had the highest rate of increase. The Granger causality test showed that NO was a cause of all respiratory system diseases experienced by patients visiting the emergency room that were examined in this study. Likewise, a significant increase in PM_{10} levels caused an increase in pneumonia and bronchitis cases. Similar to our findings, Cengiz et al.[7] reported that levels of SO_2 and PM_{10} were significantly different between warm and cold months. There was a significant relationship between the number of patients visiting the hospital and air pollutants. These results may have been due to the increase in air pollutant values

Table 4. Causality relationship between respiratory diseases and air pollutants

Causality aspect/hypothesis	F-statistics	Probability	Decision
NO is not a Granger cause of asthma.	9.41834	0.0141	H_0: Rejected
NO_2 is not a Granger cause of asthma.	6.20963	0.0346	H_0: Rejected
NO_X is not a Granger cause of asthma.	6.97894	0.0272	H_0: Rejected
PM_{10} is not a Granger cause of asthma.	1.32655	0.3334	H_0: Not rejected
SO_2 is not a Granger cause of asthma.	3.29892	0.1080	H_0: Not rejected
NO is not a Granger cause of COPD	3.62232	0.0930	H_0: Rejected*
NO_2 is not a Granger cause of COPD	4.51844	0.0635	H_0: Straight
NO_X is not a Granger cause of COPD	7.63512	0.0224	H_0: Rejected
PM_{10} is not a Granger cause of COPD	0.42223	0.6737	H_0: Not rejected
SO_2 is not a Granger cause of COPD	1.02415	0.4143	H_0: Not rejected
NO is not a Granger cause of pneumonia	68.2776	0.0462	H_0: Rejected
NO_2 is not a Granger cause of pneumonia	5.62250	0.0421	H_0: Rejected
NO_X is not a Granger cause of pneumonia	6.74649	0.0292	H_0: Rejected
PM_{10} is not a Granger cause of pneumonia	3.55909	0.0957	H_0: Rejected*
SO_2 is not a Granger cause of pneumonia	1.85472	0.2360	H_0: Not rejected
NO is not a Granger cause of URTI	4.04224	0.0773	H_0: Rejected*
NO_2 is not a Granger cause of URTI	4.53137	0.0632	H_0: Rejected*
NO_X is not a Granger cause of URTI	4.55472	0.0626	H_0: Rejected*
PM_{10} is not a Granger cause of URTI	1.43811	0.3089	H_0: Not rejected
SO_2 is not a Granger cause of URTI	1.46531	0.3033	H_0: Not rejected
NO is not a Granger cause of bronchitis	4.59706	0.0616	H_0: Rejected*
NO_2 is not a Granger cause of bronchitis	26.2474	0.0011	H_0: Rejected
NO_X is not a Granger cause of bronchitis	18.4115	0.0028	H_0: Rejected
PM_{10} is not a Granger cause of bronchitis	3.81740	0.0852	H_0: Rejected*
SO_2 is not a Granger cause of bronchitis	0.49603	0.6319	H_0: Not rejected

*Indicates statistical significance at 10% significance level.
NO: nitrogen, NO_X: nitrogen oxide, NO_2: nitrogen dioxide, PM_{10}: particulate matter$_{10}$, SO_2: sulfur dioxide, COPD: chronic obstructive pulmonary disease, URTI: upper respiratory tract infections

Table 5. Association between air pollutants and number of patients with respiratory disease-related visits

Variables	B	SE	Beta	*P*
Asthma				
Constant	1145.174	206.621	-	$P < 0.001$
SO_2	98.899	27.767	0.748	**0.005**
COPD				
Constant	720.099	77.456	-	$P < 0.001$
PM_{10}	-5.482	1.864	-0.748	**0.016**
SO_2	49.033	11.766	1.060	**0.002**
Pneumonia				
Constant	306.479	76.981	-	0.003
SO_2	42.761	10.345	0.794	**0.002**
URTI				
Constant	19356.372	2531.701	-	$P < 0.001$
NO	570.362	215.633	0.642	**0.025**
Bronchitis				
Constant	498.735	178.637	-	0.019
SO_2	106.037	24.007	0.813	**0.001**

NO: nitrogen, PM_{10}: particulate $matter_{10}$, SO_2: sulfur dioxide, COPD: chronic obstructive pulmonary disease, URTI: upper respiratory tract infections

caused by the combustion of fossil fuels for heating during the cold months, and thus, the number of patients increases in parallel.

Checking for the existence of the Granger causality relationship between time series allows one to examine whether the dynamics of each time series determine the evolution of the other time series included in the study.[17] In this study, the Granger causality test revealed a unidirectional causal relationship between NO, NO_X, and NO_2 levels and the numbers of patients with asthma, COPD, pneumonia, bronchitis, and URTI. These results meant that increased NO, NO_X, and NO_2 levels led to increased hospital visits for respiratory diseases. The United States Environmental Protection Agency (US EPA) reported that even short-term exposure to NOx can worsen respiratory diseases such as asthma, leading to increased respiratory symptoms, hospitalizations, and emergency room visits.[21] The US EPA also reported that prolonged exposure to high concentrations of NO_2 may contribute to a potential increase in susceptibility to respiratory infections and the development of asthma.[21] In our study, NO, NO_X, and NO_2 values were determined to cause higher numbers of emergency department visits by patients with asthma, COPD, pneumonia, bronchitis, and URTI. NO_X is present in the air as NO, but this species is easily oxidized to NO_2 by reacting with O_3. NO_2 is a highly toxic gas that can trigger cell damage and inflammatory processes throughout the respiratory system, from the nose to the lung alveoli.[22] Based on the results found in our study, it is thought that NO, NO_X, and NO_2 triggered inflammatory processes and caused emergency room visits.

PM is a mixture of extremely small particles and droplets in the air, consisting of various solid and liquid components such as organic and inorganic substances suspended in the air. The presence of PM in the air causes increased health risks. In particular, PM with an aerodynamic diameter of 10 µm and smaller (PM_{10}) cannot be filtered through the nose, eyelashes, or mucus in the respiratory tract. Therefore, it can reach the tracheobronchial and alveolar regions of the respiratory tract, enter the circulatory system, and cause diseases.[13] In this study, a unidirectional causal relationship was found between PM_{10} levels and pneumonia- and bronchitis-related visits to the emergency room. Accordingly, the increase in PM_{10} levels increases the number of patients with bronchitis and pneumonia visiting the emergency department. Similar to our findings, Slama et al.[12] (2019) reported a positive relationship between ambient air pollution and hospitalization, where $PM_{2.5}$ and PM_{10} had the most significant effect. Zhang et al.[13] reported that PM exposure increased hospital visits due to arrhythmia, hypertension, cerebrovascular disease, and ischemic heart disease. These results are thought to be due to the structure of PM_{10} that can reach the lung alveoli. In addition to the effect of air pollution on respiratory diseases, it is also thought that it triggers other health problems, and predicting that hospital admissions will increase when air pollution is intense and making plans in this direction will contribute to the management of diseases. In this study, it was concluded that there was no causal relationship between SO_2 levels and the number of emergency room visits due to respiratory diseases, and an increase in SO_2 levels was not a cause of an increased number of emergency room visits. Unlike our findings, Kara et al.[23] reported that SO_2 levels had a significant effect on asthma cases admitted to hospital. It is thought that this difference is due to the analysis performed. Kara et al.[23] investigated whether there was an effect according to their correlation analysis results. In our study, Granger causality was analyzed.

Moreover, according to the correlation analysis performed after the Granger causality test, a correlation was found between asthma and SO_2.

In the literature, the relationship between air pollutants and respiratory tract diseases has been tested by regression and correlation analyses. In the regression/correlation relationships established in these studies, analyses have been carried out by assuming that a causality relationship between these variables. However, the establishment of regression models by examining the causality relationship between two variables provides more successful predictions. According to Granger, before moving on to the precise mathematical representation of causality, many research papers investigating cause-and-effect relationships between stochastic processes (or random processes) use correlation, partial correlation, or the mutual information function as tools to investigate causality. Although these approaches are not entirely wrong, they do not manage the concept of causality effectively and often lead to misleading results. The main difference between these techniques and Granger causality is that these measures can provide information about the correlation-independence (influence/relationship) between processes, not whether the information provided by one stochastic process can usefully contribute to the predictability of another.[24] In the literature, there are studies using time series, similar to our study, but these studies have usually examined correlation relationships rather than causality. In the ecological time series study carried out by Nascimento et al.[25] (2016), similar to our findings, it was concluded that respiratory diseases led to hospitalizations as a result of exposure to a large number of air pollutants such as NO_2, PM_{10}, CO, and SO_2. In another study using an ecological time series, César et al.[22] estimated the relationship between air pollutants and hospitalization due to respiratory diseases. Comparing mortality associated with respiratory diseases to estimated daily levels of air pollutants over about one year, the results of their study revealed an association between exposure to NO_X and mortality from respiratory diseases. Air pollution involving O_3, PM, diesel exhaust particles, NO_2, and SO_2 increases the permeability of the airways, facilitates the penetration of allergens into the mucous membranes, and causes interactions with immune system cells.[26] As a result, air pollution is thought to play an inflammatory role in the airways of predisposed patients and is considered to be the cause of emergency visits and admissions.

In this study, a regression analysis was performed after the Granger causality tests to make more successful predictions. As a result of the analysis, it was determined that there was a significant relationship between asthma, COPD, pneumonia, and bronchitis cases involving visits to the emergency department and concentrations of SO_2, as well as relationships between visits for COPD cases and levels of PM_{10} and between visits for URTI cases and levels of NO. SO_2 levels were a predictor of visits to the emergency department due to asthma, COPD, pneumonia, and bronchitis, PM_{10} levels were a predictor of bronchitis-related visits, and NO levels were a predictor of visits related to URTI. Slightly differently from our findings, Saygın et al.[8] (2017) reported a strong correlation between PM_{10} and COPD, a weak correlation between PM_{10} and asthma, and a correlation between SO_2 and COPD but not asthma. Like our results, Kara et al.[23] found a correlation between SO_2 and PM_{10} levels and asthma cases. Çapraz et al.[27] reported that short-term exposure to PM_{10}, $PM_{2.5}$, and NO_2 was associated with increased hospital admissions. Similar findings are thought to be associated with the usage of the same analyses and parameters.

This study had some limitations. First, the study was conducted in a single region, data from a period of one year were used, and CO and $PM_{2.5}$ data could not be obtained from the system for the examined region. Unlike other studies in the literature, the use of time series and the Granger causality test (Appendix 1) provided more substantial evidence of the cause-and-effect relationships, constituting the study's strength. Another strength of the study is that it was conducted in a region with brick, paint, and textile factories, where inhaled dust sources such as tobacco and vine leaves are grown, and a main road, which is a main truck transport route. The results of the study revealed a causal relationship between pollutants such as N_0 and emergency room visits for asthma and COPD. However, respiratory tract infections and air pollutants also had an increasing effect on asthma and COPD visits during the same period, which could be considered a limitation.

CONCLUSION

It was determined that there was a Granger causality relationship between increased levels of air pollutants such as NO, NO_X, NO_2, and PM_{10} and the numbers of patients visiting the emergency department. For this reason, the values of these air pollutants should be considered while preparing emergency department shift schedules, creating maintenance plans, and budgeting. Hospital/emergency department visits due to respiratory diseases are closely related to cold weather but are also closely associated with increased outdoor air pollution rates. Since the number of inpatients is also closely related to the number of emergency department visits, knowing in which months the number of patients will increase in the coming periods would affect disease and hospital management. Therefore, understanding and analyzing the effects of air pollutants on increases in the number of patients visiting the emergency department is critical in the appropriate management of diseases, increasing the quality of health care, and preventing hospital overcrowding. It is recommended that studies involving more extended time series in a larger region should be conducted in the future. Additionally, studying the causal relationship between air pollutants and diseases other than those of the respiratory tract will contribute to the literature.

Ethics

Ethics Committee Approval: Approval was obtained from Tokat Gaziosmanpaşa University Ethics Committee for conducting the study (date/number: 21.05.2024/09.12).

Informed Consent: Retrospective study.

Footenotes

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Appendix 1. Granger causality test

This section aims to identify causal relationships between time series that are useful in forecasting.

Causality implies that the estimated future values of a time series variable are affected by the past values of another related time series variable.[28] According to Granger (1969), causality refers to the relationship between X and Y in the presence of two variables. If the prediction of variable X is better than the prediction based only on lagged values of X, then variable Y is a Granger cause of X.[29] The formulae used for the Granger causality test are given in equations 1 and 2.

$$X_t = \sum_{i=1}^{m} a_i X_{t-i} + \sum_{j=1}^{m} \beta_j Y_{t-j} + \lambda_1 t + u_{1t} \quad (1)$$

$$Y_t = \sum_{i=1}^{m} \gamma_i Y_{t-i} + \sum_{j=1}^{m} \delta_j X_{t-j} + \lambda_2 t + u_{2t} \quad (2)$$

In equations 1 and 2, t is the time variable, and u_1t and u_2t are the error terms. u_1t and u_(2t) are assumed to be uncorrelated.

In equation 2, if δj is different from zero, it can be stated that there is a Granger causality relationship from X to Y. If βj coefficients are significantly different from zero, it can be stated that there is a Granger causality relationship from Y to X. The null hypothesis in the Granger causality test is "X is not a Granger Cause of Y".[30]

In the Granger causality test, the null hypothesis is "independent variables are not Granger causes of the dependent variable," while the alternative hypothesis is "independent variables are Granger causes of the dependent variable".[28] The null hypotheses for this study were as follows; "CO is not a Granger cause of asthma. SO_2 is not a Granger cause of asthma. PM_{10} is not a Granger cause of asthma. CO is not a Granger cause of COPD. SO_2 is not a Granger cause of COPD. PM_{10} is not a Granger cause of COPD. CO is not a Granger cause of pneumonia. SO_2 is not a Granger cause of pneumonia. PM_{10} is not a Granger cause of pneumonia. CO is not a Granger cause of bronchitis. SO_2 is not a Granger cause of bronchitis. PM_{10} is not a Granger cause of bronchitis. CO is not a Granger cause of URTI. SO_2 is not a Granger cause of URTI. PM_{10} is not a Granger cause of URTI."