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The Relationships between Air Pollution, Warming, and Health in Tehran Metropolis, Iran, during 2015–2019

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ABSTRACT

Introduction: Since global warming and air pollution was caused by human activities have increased dramatically in recent decades, studies have been conducted to determine how environmental parameters and air pollutants interact and, subsequently, how these pollutants affect ecosystems and human health. Accordingly, this study aimed to investigate the relationship between temperature and air pollutants in Tehran, Iran, in order to determine whether warming is associated with an increase in air pollutants.

Materials and Methods: During 2015-2019, Iran Air Quality Monitoring Station (AQMS) and the Landsat 8 satellite were employed to retrieve data on pollutants such as PM, CO, O_3, NO_2, SO_2, and air quality index (AQI), as well as climate-related metrics including ambient temperature and land surface temperature (LST). Pearson correlation coefficient and linear regression model were used to analyze the data.

Results: A positive correlation was found between temperature variables and PM_{10} ($\rho = 0.29$, $p = 0.001$) and O_3 ($\rho = 0.55$, $p = 0.001$) pollutants. PM_{10} and O_3 levels were evaluated by 0.46 (95% Confidence Interval (CI) = (0.25, 0.67), p = 0.001) and 1.13 (95% CI = 0.89, 1.37), p = 0.001) units for each one-unit rise in temperature.

Conclusion: Given the fact that temperature predominantly evidenced a significant synergistic association with PM_{10} and O_3, it was determined that there was no substantial positive association between all pollutants and warming.

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Introduction

Globally, as a result of the increase in greenhouse gas (GHG) emissions, the temperature has been risen substantially, resulting in more severe and longer heat waves, as well as longer periods of drought, higher levels of air pollution, wildfires, and floods induced by the increasing climate change [1]. Growing global warming and ambient air pollution in highly populated developing countries might pose significant health implications (Figure 1) [2].

Based on the recent empirical evidence, changing climate may considerably enhance respiratory difficulties and death in individuals suffering from long-term lung disorders including asthma and chronic obstructive pulmonary disease (COPD) [1]. Approximately 12–16 million Americans suffer from COPD, which is the third primary cause of death in the United States. While smoking is the

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major cause of COPD in industrialized nations, exposure to polluted air also significantly contributes to its prevalence and severity [3]. Several studies have demonstrated that nitrogen dioxide (NO_2) is associated with an increased risk of allergic rhinitis (AR) and asthma in adults [4]. The global rise in asthma prevalence and severity may be attributed to the interaction between air pollution and global warming [5]. In a systematic investigation, it was found that O_3, $PM_{2.5}$, and NO_2 emissions, coupled with the climatic parameter of temperature, contributed to low birth weight (LBW) and preterm birth (PB) enhancement in Madrid (Spain) during 2001–2009 [6].

Previous temperature fluctuations and air pollution have a significant impact, either directly or indirectly, on fatalities and health consequences [7]. As a result of climate change, heat waves may become more frequent and thermal stress will be created, which will increase the mortality rate due to heat-related diseases worldwide [8]. A stronger relationship was observed between PM_{10}, SO_2, and NO_2 and mortality at high temperatures compared to moderate temperatures [9]. A study examined 18,921 migraine cases in Seoul, South Korea, between 2008 and 2014 and concluded that exposure to air pollution, particularly during periods of high temperatures, is likely to trigger migraines [10]. An increase in the prevalence of eczema has been shown to be associated with a series of environmental parameters, including high temperatures and low relative humidity, as well as PM_{10}, NO_2, and SO_2 pollutants in Shanghai, China [11]. Another study reported that the emission of heat waves from heating equipment during the winter is one of the key factors contributing to the enhancement of $PM_{2.5}$ in more than 75% of central and eastern China [12]. Based on the findings of a study, a decline in forced vital capacity (FVC) of the lung of 0.70% (95% confidence interval: -1.24, -0.20) was associated with a rise of 5 ^{0}C in the mean temperature. As a result, there was a correlation between an increase in temperature and a decrease in lung function [13]. Additionally, possible stimulatory effects of high temperatures as well as pollutants such as NO_2, PM_{10}, and O_3 can also result in an increased likelihood of premature births [14]. As part of a similar investigation, it was revealed that a significant correlation existed between the maximum air temperature and PM_{10}, which has been shown to have synergistic effects on elderly mortality [15].

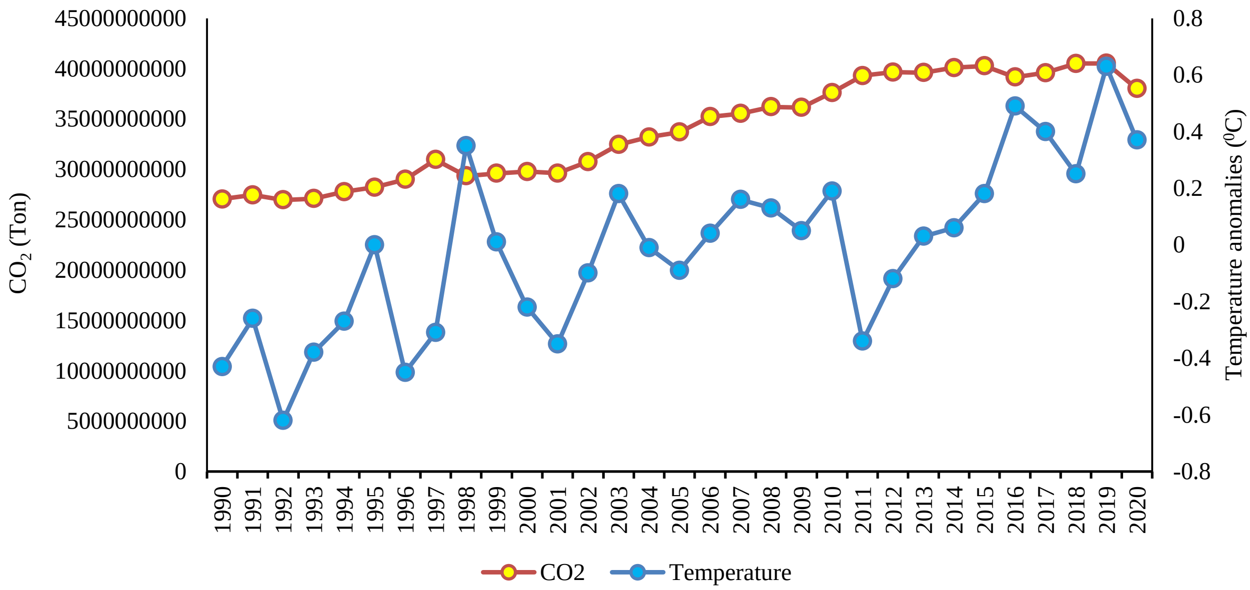

Figure 1: The trend of the global increase in carbon dioxide emissions and temperature from 1990 to 2020 [16,17].

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Being exposed to heat and air pollution is connected with negative health consequences, such as cardiovascular and respiratory disorders, and hence the cumulative effects of both heat and polluted air may allow these fallouts to be more severe [18]. It should be noted that several documents contradict the mentioned conclusions and indicate that the interaction between high levels of air pollution and colder temperatures may be synergistic. Several researchers examined how $PM_{2.5}$ affected cardiovascular diseases (CVDs) between 1991 and 2006 in New York and found that an increase of 10 $\mu g.m^{-3}$ of this pollutant caused a 1.37% increase in CVDs, and these impacts were more profound during winter months and on days with low temperatures [19]. Cold air dramatically exacerbated the influence of PM and SO_2 on COPD in Chengdu, China [20]. Another research showed that both heat and cold were linked with an exacerbation of COPD-related respiratory problems [3]. The findings of a survey revealed that both air pollution and low temperatures were significantly associated with an increased risk of CVD death among individuals over sixty years of age [21]. In an analysis, the effects of PM pollutants on blood pressure were larger at low temperatures than at high temperatures, and the researchers concluded that low temperatures and high pollution might operate in collaboration to elevate blood pressure in adults [22]. Nevertheless, it has been shown that climatic conditions and air pollution have a nonlinear impact on hand, foot, and mouth (HFMD) epidemics [23]. Considering the contradicting observations and the growing trend of global warming, this research question (*Q1*) arises as whether high temperature has a diminishing or amplifying effect on air pollution?

Climate is known to have a significant contribution in the creation and development of air pollution. Conversely, air pollution also affects climate via the scattering and absorbing of radiation. Therefore, there is still an uncertainty regarding the cause-and-effect interaction that exists between these two components. In tropical and temperate climates, the correlation between air pollution and precipitation and temperature is mostly negative and positive, respectively. The climate-pollution interaction is dominated by precipitation under moist and unpolluted circumstances, and thereby has a negative relationship. In the temperature-pollution interaction, air pollution exerts a stronger influence than temperature [24]. Although there is substantial empirical evidence indicating high temperature and air pollution have synergistic impacts on health, few investigations have addressed how the two components interact with each other [25].

Iran is increasingly facing numerous environmental challenges [26] including severe air pollution [27]. In Iran, there was a positive correlation between the amount of PM and the number of people diagnosed with COVID-19 [28]. Hence, the primary objective of this research is to find a response to *Q1*, which will be accomplished by analyzing the correlation between air pollution and temperature in Tehran, as a hotspot of pollutants, over the course of four years (2015–2019) using proximal and space-based frameworks.

Materials and Methods

Study area

The capital of Iran and the most populous metropolitan area in the country, Tehran, is situated at 35° 41′ N and 51° 26′ E [29]. Its elevation ranges from 900 to 1800 meters above sea level, and the climate in its northern region is characterized by cold and dry conditions, while the climate in its southern area is characterized by weather that is relatively hot and dry. The average temperature is between 15 ^{0}C and 18 ^{0}C throughout the year, with local variations of up to 3 ^{0}C. As a metropolis, this city has about 10555 people living per square kilometer, and it measures approximately 730 square kilometers in size. Considering the fact that the city already has an estimated population of around 13 million, there is a substantial amount of interest in migrating to Tehran due to its importance as a key organization, commercial, and technological hub. This makes its pollution among the most pressing concerns for the environment [30].

Data sources

Ambient air pollution sensors are instruments that have the power to detect pollutants in the air and evaluate atmospheric conditions. These monitors are used in many towns. Through the online platform, the obtained data can be submitted to analytics software in addition to being rendered to social media. This survey's dataset contains daily findings of monitors measuring carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), Sulphur dioxide (SO_2), particulate matter > 10 µg. m^{-3} (PM_{10}), and particulate matter < 2.5 µg. m^{-3} ($PM_{2.5}$). Data about air pollutants as well as an air quality index (AQI) are recorded and transmitted to the Department of Environmental Monitoring and Management each day at eleven in the morning [30]. This study obtained the mean daily levels of air quality measured by sensors across Tehran directly from the Iranian AQMS, which can be accessed at: https://aqms.doe.ir/. These measurements were taken over a period of four years between January 2015 and December 2019.

Data from the Weather Underground (WU) World Meteorological Database, which is accessible at https://www.wunderground.com, are used in the compilation of the meteorological data. Since 1993, this website has provided observational data gathered from over 250,000 different airports. Data from these airport terminals are compiled into this database. Approximately 6000 computer-based weather stations are available at world airports, and the data from these stations are updated every 1, 3 and 6 hours. Mehrabad Airport is one of the airports connected to this network, situated at 35° 41' N and 51° 19' E in Tehran. Figure 2 presents a map of the study area that pinpoints the locations of weather and AQMS.

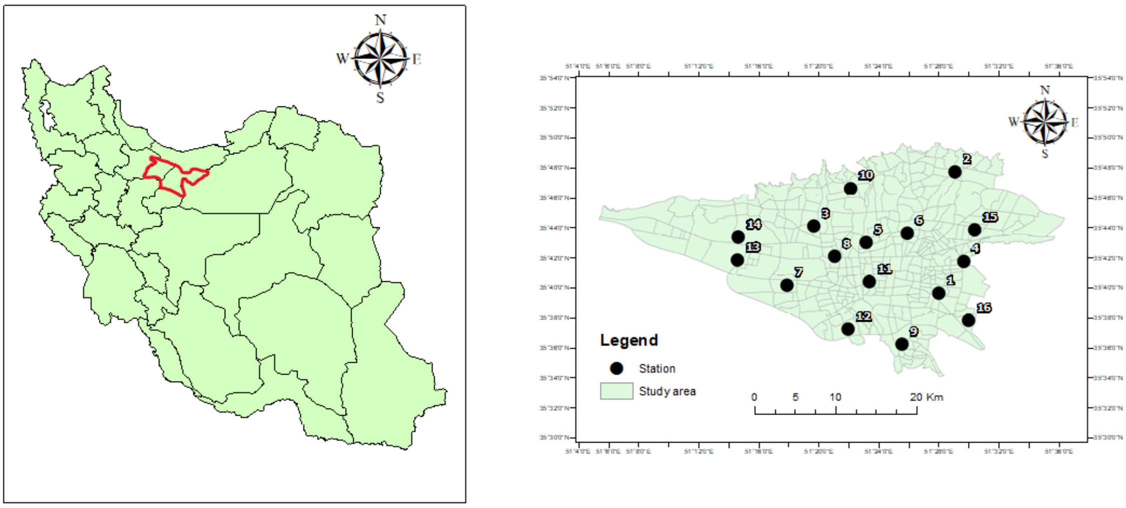

Figure 2: The map of the study area. The black dots on the map indicate the precise locations of air pollution monitoring stations situated within the city of Tehran.

A parameter called land surface temperature (LST) plays an essential role in many different disciplines, including climate change, global warming, hydrology, and urban land use [31]. The rise in temperature of the Earth's surface contributes to the elevation of the ambient temperature. Consequently, by taking into account LST in addition to ambient temperature, the correlation between heat and air pollution may be assessed with greater clarity and precision. The LST, which represents the temperature of the Earth's surface in Kelvin, is an essential remote sensing characteristic employed in investigations predicting hydrological systems as well as global energy balance. It is also used for the analysis of agricultural and plant health, soil moisture, and severe heat phenomena such as natural catastrophes (including volcanoes erupting and forest fires), as well as the impacts of urban heat islands [32,33]. With the launch of Landsat 8, the most recent member of the Landsat series, new opportunities have been created for a broader understanding of Earth phenomena based on remote sensing data [31]. This survey directly retrieved the LST data (calibrated into Celsius) from the Landsat 8 satellite during the timeframe described by uploading the polygon of Tehran city into the Sentinel Hub system (accessible at https://apps.sentinel-hub.com/eo-browser/).

Data processing and statistical analysis

Statistical analysis of the data was conducted employing the STATA version 14 software. Indicators including mean and standard deviation were used related to descriptive statistics. A scatter diagram was also drawn in order to visually correlate the two variables. For analytical statistics, the relationship between air pollution, temperature, and LST variables was assessed using the Pearson correlation coefficient test. Also, a separate linear regression model was fitted to determine the relationship between independent variables (temperature and LST) and each of the independent variables of air pollution. The 0.95 confidence range and p-value for regression model coefficients were measured. The significance level for the statistical test and regression model coefficients was determined to be < 0.05.

Results

The results showed that the mean and standard deviation of AQI, $PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3, and CO were 87.1 ± 26.1, 87.7 ± 24.9, 50.5 ± 15.4, 24.3 ± 5.4, 61.0 ± 17.0, 33.3 ± 19.9, and 37.2 ± 10.2, respectively. The mean and standard deviation of the temperature was 18.8 ± 9.8 (Table 1). The statistical test revealed a statistically significant ($p = 0.001$) direct connection between temperature and PM_{10} and O_3 variables. In other words, temperature increased by increasing the concentration of PM_{10} and O_3. There was a statistically significant negative correlation between temperature and CO ($p = 0.044$) as well as SO_2 ($p = 0.005$) variables. In addition, a statistically significant ($p = 0.001$) direct association was shown between LST and PM_{10} and O_3 variables. In other words, when LST rises, O_3 and PM_{10} concentrations rise as well (Table 2). According to linear regression, PM_{10} rose by 0.46 degrees for each unit increase in temperature ($p = 0.001$). Furthermore, a unit increase in the LST value led to a 0.16-unit increase in PM_{10}, which was statistically significant ($p = 0.001$). Similar results were documented for $PM_{2.5}$. In addition, the values of temperature and LST rose by 1.13 and 0.32 per unit rise in O_3 ($p = 0.001$) (Table 3). According to the distribution plot, PM_{10} and O_3 variables had a linear relationship with temperature and LST (Figure 3).

Table 1: Descriptive statistics concerning air pollution variables, temperature, and LST (n = 225)

Variable	Min, Max	Mean ± S.D
AQI	31, 163	87.1 ± 26.1
$PM_{2.5}$	35, 163	87.7 ± 24.9
PM_{10}	8, 100	50.5 ± 15.4
SO_2	14, 58	24.3 ± 5.4
NO_2	28, 104	61.0 ± 17.0
O_3	6, 134	33.3 ± 19.9
CO	21, 83	37.2 ± 10.2
Temperature	-0.3, 35.5	18.8 ±9.8
LST	-81.6, 51.7	18.6 ± 51.7

*S.D: Standard Deviation; Min: Minimum; Max: Maximum.

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Table 2: Correlation between air pollution variables, temperature and LST (n = 225)

Variable	Temperature		LST	
	ρ	P	ρ	P
AQI	-0.03	0.687	0.09	0.196
$PM_{2.5}$	-0.04	0.576	0.06	0.409
PM_{10}	0.29	0.001	0.29	0.001
SO_2	-0.19	0.005	-0.06	0.362
NO_2	-0.05	0.454	0.08	0.249
O_3	0.55	0.001	0.43	0.001
CO	-0.14	0.044	-0.01	0.870

*ρ: Correlation test Pearson; P: P-Value.

Table 3: Relationships between temperature or LST with air pollution variables (n = 225)

Dependent Variables	Independent Variables			
	β (95% CI) Temperature	P	β (95% CI) LST	P
AQI	-0.08(-0.43, 0.23)	0.678	-0.08(-0.21, -0.04)	0.014
$PM_{2.5}$	-0.10(-0.44, 0.24)	0.576	0.05(-0.07, 0.18)	0.409
PM_{10}	0.46(0.25, 0.67)	0.001	0.16(0.09, 0.24)	0.001
SO_2	-0.11(-0.18, -0.03)	0.005	-0.02(-0.04, 0.01)	0.362
NO_2	-0.09(-0.33, 0.15)	0.454	-0.05(-0.13, -0.04)	0.030
O_3	1.13(0.89, 1.37)	0.001	0.32(0.23, 0.41)	0.001
CO	-0.14(-0.28, -0.01)	0.044	0.01(-0.05, 0.05)	0.507

* β: Linear regression coefficient; CI: Confidence Interval; P: P-Value.

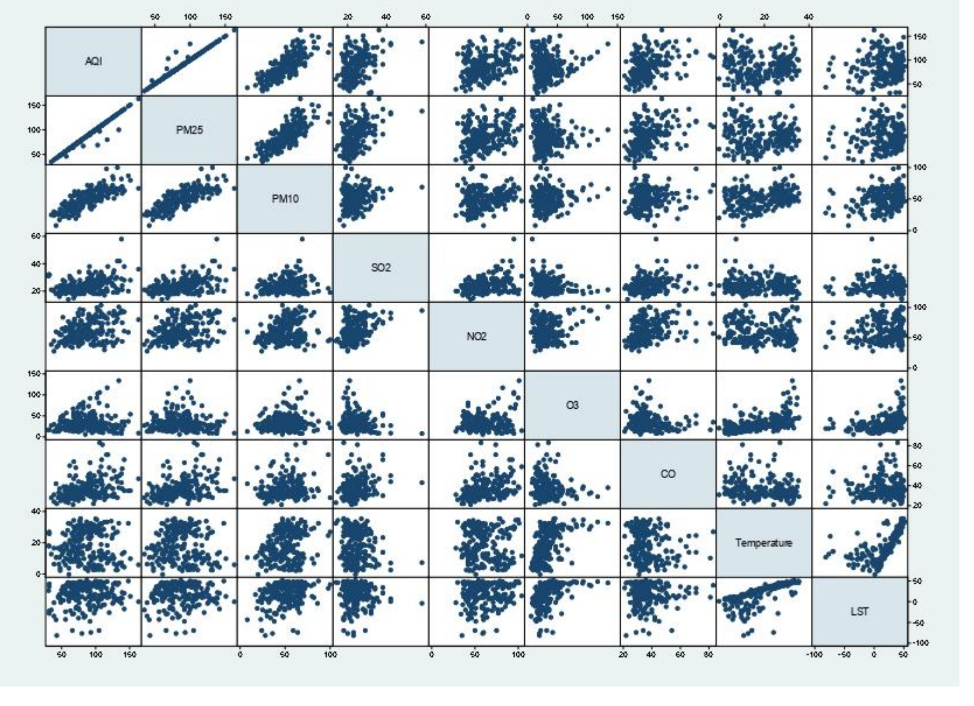

Figure 3: Distribution diagram between air pollution variables with temperature and LST

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Discussion

The quality of air is affected by meteorological conditions [34], and based on the findings of this research, it was concluded that temperature and pollutants in Tehran are interrelated. Considering that there was a significant correlation between O_3 and PM, it can be argued that higher temperatures result in enhanced emissions of O_3 and PM precursor chemicals. By increasing temperature, the reactions that produce O_3 pollutants become significantly faster [35] resulting from solar radiation, which increases the rate at which they are formed. Moreover, PM and black carbon may enhance the absorption of sunlight [36]. In response to *Q1*, it can be concluded that high temperature has an amplifying effect on some important air pollutants. The findings indicated an increase in the health impacts resulting from elevated levels of O_3 and PM in Tehran, under a hypothetical scenario of future higher temperatures. The relationship between PM_{10} and O_3 levels and apparent temperature was analyzed and showed an association between the levels of PM_{10} and O_3 pollutants under high temperature conditions [37]. A study carried out in Berlin (Germany) and Lisbon (Portugal) utilized a variety of Poisson regression models to investigate the interrelations between temperature and O_3 and PM. The researchers highlighted the fact that when high temperature is coupled with high levels of pollution in the air, the threat of illness and death enhances [38]. As a consequence of climate change, both temperature and O_3 factors are expected to rise, and they have been found to stimulate autonomic nervous system dysfunction [39]. Changing temperatures and precipitation patterns causes the O_3 season to extend, and as a result the concentration of gas increases in some regions. Additionally, other aspects of climate change, such as wildfires and soil emissions, may result in excess nitrogen-containing chemicals being released into the atmosphere [40].

From the environmental viewpoint, natural glaciers, mountain snows, and biodiversity are all vulnerable to the consequences of global warming [41]. It has been demonstrated that the Arctic is warming more rapidly than the rest of the world [42]. The results of regression analysis and ANOVA tests indicated a positive link between the severity of heat in Seoul, South Korea islands, and the levels of CO, NO_2, SO_2, PM [43]. Some studies have indicated that climate change will independently contribute to an elevation in midsummer surface O_3 levels in regions already affected by pollution. This increase is projected to range from 1 to 10 parts per billion (ppb) over the next few decades. The most significant impacts are expected to occur in metropolitan areas and during episodes of heightened pollution. The imposition of a climate penalty necessitates the implementation of more stringent emission regulations in order to achieve a specified air quality benchmark [44]. With the predicted rising temperature owing to climatic change, the necessity to explore the implications of thermal stress has already been emphasized [3], and a more profound understanding of the causes of climate change may assist in the creation of mitigation plans [39]. To further describe interactions from a statistical perspective, it is proposed that practices be appointed to reduce the problem of scarcity of observations by addressing second- and third-order interactions between variables [45]. Moreover, it is imperative to adopt more effective strategies for controlling air pollution as well as the mitigation of greenhouse gas (GHG) emissions in projects intended to prevent rising temperatures and following global warming [25,7]. In this regard, the development of green areas and the promotion of urban vegetation may alleviate the effects of urban heat islands that are caused by global warming [46]. Moreover, the utilization of renewable energies (RE) such as wind, solar photovoltaic (PV), concentrated solar power (CSP), geothermal, hydropower, tidal power, and biofuels such as bioethanol and biogas will result in enormous reductions in carbon emissions and air pollutants [47]. Eventually, an international attempt is required to lower the speed of climate change and the danger of polluted air, especially considering that both are global crises [48].

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Conclusion

Due to the dramatic increase in global temperature, studies have been conducted on the simultaneous effects of high temperature and pollution. As a result of these surveys, which have discussed the synergistic impact of temperature and pollutants on human health, it has been concluded that both high temperature and pollution negatively affect human health. This research aimed at examining the temperature-pollutant relationship from an environmental perspective, and finding out whether high temperature can increase the emission of pollutants, and if so, what pollutants are likely to increase by high temperature. According to the findings of the present study, it was concluded that there was no significant positive correlation between all pollutants and warming. Consequently, it is likely that the health effects caused by O_3 and PM_{10} in Tehran increase during episodes of higher temperatures. Regardless of significance, temperature and LST correlation with certain pollutants (including SO_2 and NO_2) and AQI was negative. Therefore, it is not true that all kinds of pollutants are synergistic with high temperature in Tehran, which should be taken into consideration. Future studies should concentrate more on diseases caused by O_3 and PM that are exacerbated by warming. More research is needed to assess these relationships over a more extended timeframe and with additional parameters, particularly solar radiation, wind, humidity, and atmospheric pressure, in order to obtain a deeper understanding of the interactions. Additionally, in light of the fact that PM, as well as O_3, are one of the most prominent air pollutants, especially in Tehran, policymakers should adopt more appropriate and efficient strategies to combat climate change and air pollution.

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Conflict of interests

The authors state that this study is unaffected by any potential conflict of interest.

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Ethical Considerations

The authors have fully addressed ethical issues including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publishing and/or submission, redundancy, etc.

Code of Ethics

Code of Ethics is not applicable for the current study.

Authors' Contributions

The authors declare their involvement in the research as follows:

Kosar Danshipour was responsible for the conceptualization, gathering of data, and creation of the initial manuscript. Armin Naghipour carried out the statistical analysis and data processing. Abdullah Kaviani Rad was responsible for reviewing and revising the manuscript, coordinating the team, and supervising the project.

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