The effect of seasonal temperatures on the levels of air pollutants in rural and urban areas in Iraq

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ABSTRACT: Iraq is one of the regions most affected by climate change around the world. These multidimensional effects of climate and pollution must be taken into consideration when estimating both climate and air pollution-related impacts, in order to develop appropriate health policies and measures to address both current and future climate and pollution challenges. The study was conducted in the Iraqi governorate of Salah al-Din, during the fall, winter and spring seasons of the year 2021-2022, with the aim of evaluating the level of pollutants in the atmospheric air for three regions: Abotuama rural area, Baiji oil refinery and the city of Tikrit. The concentrations of each of the toxic gases were measured: SO_2, NO, NO_2, HCL, HF, TVOC, CO_2 and CO, as well as temperatures. Significant differences were found between the study locations and seasons for all the variables that were tested, as Baiji refinery recorded the highest concentrations of SO_2, NO, NO_2, HCL, FH and TVOC at 3.5 ppm, 10.78 ppm, 7.475 ppm, 13.1 ppm, 0.8 mg m^{-3} and 15.25 ppm, respectively. The site of Tikrit recorded the highest concentrations of CO2 and CO, which were 1016 ppm and 29.85 mg m^{-3}, respectively. While the spring season recorded the highest concentrations of SO_2, HCL, TVOC and CO compounds, followed by the winter season of NO_2, FH and TVOC compounds, the temperature rates were identical in the three study sites and during the fall, winter and spring seasons, reaching 30.25, 12.5 and 31 °C during the three seasons, respectively. The results of analyzing the relationship between temperature and pollutant concentrations showed that SO_2, NO, HCl, and CO increase in hot seasons, while NO_2, HF, TVOC, and CO_2 pollutant concentrations increase during cold seasons.
Keywords: air pollution; CO compounds; air temperature.

Efeito das temperaturas sazonais nos níveis de poluentes atmosféricos em áreas rural e urbana, no Iraque

RESUMO: O Iraque é uma das regiões mais afetadas pelas mudanças climáticas em todo o mundo. Os efeitos multidimensionais do clima e da poluição devem ser levados em consideração ao estimar os impactos climáticos e suas relações com a poluição do ar, a fim de desenvolver políticas e medidas de saúde apropriadas para enfrentar os desafios atuais e futuros do clima e da poluição. O estudo foi realizado na província iraquiana de Salah al-Din, durante as estações de outono, inverno e primavera do ano 2021-2022. Objetivou-se avaliar o nível de poluentes no ar atmosférico de três regiões: área rural de Abotuama, a refinaria de petróleo de Baiji e a cidade de Tikrit. Foram avaliadas as concentrações dos seguintes gases tóxicos: SO_2, NO, NO_2, HCL, HF, TVOC, CO_2 e CO, em conjunto com as temperaturas do ar. Foram encontradas diferenças significativas entre os locais de estudo e as estações para todas as variáveis testadas, pois a refinaria de Baiji registrou as maiores concentrações de SO_2, NO, NO_2, HCL, FH e TVOC, equivalentes a 3,5 ppm, 10,78 ppm, 7,475 ppm, 13,1 ppm, 0,8 mg m^{-3} e 15,25 ppm, respectivamente. A cidade de Tikrit registrou as maiores concentrações de CO_2 e CO, sendo de 1016 ppm e 29,85 mg m^{-3}, respectivamente. Enquanto, que na estação da primavera foram registradas as maiores concentrações dos compostos SO_2, HCL, TVOC e CO, seguida pela estação do inverno dos compostos NO2, FH e TVOC. As taxas de temperature do ar foram idênticas nos três locais de estudo e durante as estações de outono, inverno e primavera, atingindo 30,25, 12,5 e 31,0 °C durante as três estações, respectivamente. Os resultados da análise da relação entre a temperatura do ar e as concentrações de poluentes mostraram que SO_2, NO, HCl e CO aumentam nas estações quentes, enquanto as concentrações dos poluentes NO_2, HF, TVOC e CO_2 aumentam nas estações frias.
Palavras-chave: poluição do ar; compostos de CO; temperatura do ar.

1. INTRODUCTION

The continuous increase in emissions of carbon dioxide and other anthropogenic greenhouse gases is significantly changing the climate at the global and regional levels. As in other parts of the world, Iraq has seen a gradual rise in warming and a decrease in average precipitation. Climate

scenarios for the next century predict that warming will be associated with more frequent, intense and prolonged heat waves (RODRIGUEZ et al., 2019).

Climate change is likely to affect air pollution levels in urban areas, because the generation and spread of air pollutants, such as ozone and particulate matter, depend in part on local patterns of temperature, wind, solar radiation and precipitation. Air quality is expected to worsen in some areas, due to the increased frequency of forest fires that release gaseous and particulate pollutants into the atmosphere. In addition, changes in wind patterns and desertification will modify the long-range transport of pollutants from human activities and biomass burning (BHUYAN et al., 2022).

Climate change and air pollution are intrinsically linked, since greenhouse gases and air pollutants originate from the same source, which is the combustion of fossil fuels (Aziz et al., 2022). Combustion processes emit greenhouse gases such as carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4), and air pollutants such as particulate matter (PM), carbon monoxide (CO), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) (ANENBERG et al., 2020). Climate change and current and future air pollution trends, locally and globally, balance in determining air quality: on the one hand, the decrease in anthropogenic emissions, resulting from the implementation of emissions control legislation adopted in each country and improvements in the energy sector; On the other hand, the effects of climate change lead in most cases to increased levels of pollution (AZIZ et al., 2022).

Climatic factors affect particle concentrations to different degrees depending on the chemical components of the particles, on the one hand, higher temperatures lead to an increase in sulfate dust due to faster oxidation of sulfur dioxide, and on the other hand, they lead to a decrease in particle nitrate concentrations due to an increase in gas phase transition (NGUYEN et al., 2019). However, the nitrate burden is expected to increase under climate change along with all other aerosols, except sulfate (LIAO et al., 2021).

Another important link between climate and air quality is that the primary products of combustion processes (such as carbon monoxide, non-methane volatile organic compounds, nitrogen oxides, sulfur dioxide, black carbon and organic carbon dust) and some secondary pollutants have the potential to increase global warming directly or indirectly. Carbon monoxide, non-methane volatile organic compounds, and nitrogen oxides cause a decrease in the oxidizing potential of the atmosphere, which increases the lifetime of methane, which is one of the most important warming factors. Instead, nitrate particles, as well as aerosols of organic carbon, have a cooling effect on the climate. SO_2 also partially converts into sulfur particles with quenching potential and partially reacts with black carbon, which has a strong heating effect (GAO et al., 2018).

The current study aims to investigate the relationship between average temperatures and concentrations of atmospheric air pollutants using some statistical methods in three different regions within the Iraqi province of Salah al-Din.

2. MATERIAL AND METHODS
2.1. Modeling site and study period
The study included the selection of three areas for collecting air samples and testing the percentage of pollutants, namely: the first area; Abotuama area, north of Tikrit city (controlled rural area), the second area; Baiji Oil refinery, north of Tikrit city, third area; Tikrit city is the center of Salah ad-Din Governorate in the north of the Republic of Iraq. Two points were identified within each chosen site for collecting air samples, and the study was extended for the period from October 2021 to April 2022.

2.2. Air sampling method
Samples were collected and atmospheric air pollutants were quantified at all selected sites using environmental monitoring equipment according to the method of GrayWolf Sensing Solutions (ABDUL-WAHAB, 2018), which is a fully integrated system for simultaneous measurements of atmospheric parameters, toxic gases, and air velocity. The WolfPackModular was used. The Area Monitor, integrated with its own probes, WolfSense PC package and Advanced Report Generator (ARG) were used to load the calculated data, and the studied atmospheric air pollutants were estimated for an average time of 15 minutes.

The studied atmospheric air pollutants: the concentrations of the following toxic gases were estimated: sulfur dioxide (SO_2), nitrogen oxide (NO), nitrite (NO_2), hydrochloric acid (HCL), hydrogen fluoride (HF), carbon dioxide (CO_2) and carbon monoxide (CO).

2.3. Statistical analysis
After collecting the data, it was sorted and arranged using the Microsoft Office Excel program, then a comparison was made between the averages of the studied pollutants within the seasons and regions of the study according to the Duncan Mutable Range method at a probability level ($P \leq 0.05$) using the Statistical analysis system (SAS) program. Then, the graphs were drawn using Microsoft Office Excel according to the method mentioned (AL-ZUBAIDY; AL-FALAHY, 2016).

Advanced statistical analyzes were also conducted to find the Pearson correlation coefficient, simple linear regression analysis, and the coefficient of determination to show the effect of seasonal temperature rates on the concentrations of the gases studied using the SPSS statistical analysis program as mentioned in (AL-ZUBAIDY; ALJIBOURI, 2022).

3. RESULTS
3.1. Levels of atmospheric air pollutants within the study locations and seasons
The gaseous pollutants detected during the current study were SO_2, NO, NO_2, HCL, HF, TVOC, CO_2 and CO. The results indicated that there is a spatial and temporal variation in the recorded concentrations of all the monitored gaseous pollutants.

The levels of atmospheric air pollutants that were measured within the study locations and seasons shown in Figure (1a-i) showed that there were significant differences among them for all the variables studied, as it was noted with regard to the concentration of SO_2 (Figure 1a) that the highest recorded value was 3.5 ppm at the Baiji refinery site.

During the spring season, while the lowest concentration was 0.05 ppm at the site of Abotuama during the winter season, and for the concentration of NO (Figure 1b), the values ranged between 10.78 and 0.75 ppm during the autumn season at the site of the Beiji refinery and Abotuama, respectively, and for the concentrations of NO_2 (Figure 1c)

The highest value was recorded at 7.475 ppm at the Baiji refinery site during the winter season, while the lowest value was 0.525 ppm at the Abotuama site during the autumn season. For the concentration of hydrochloric acid HCL (Figure 1d), the highest value was significantly 13.1 ppm at the Baiji refinery site during the fall and spring seasons, while the lowest value was 0.53 ppm at the Abotuama site during the winter season.

The highest concentration of hydrogen fluoride (FH) was recorded at 0.8 mg/m³ at the Baiji refinery site during the winter, while the lowest concentration was 0.025 mg/m³ at the Abotuama site during the fall (Figure 1e). The concentrations of Total Volatile Organic Compounds (TVOC) (Figure 1f) ranged between 15.25 ppm at the Baiji refinery site during the winter and spring seasons, and 0.35 ppm at the Abotuama site during the fall season. For carbon dioxide (CO_2) (Figure 1g), the highest concentration was 1016 ppm in the Tikrit site during the winter season, while the lowest concentration was 205 ppm in the Abotuama site during the autumn season. As for carbon monoxide (CO) (Figure 1h), the highest concentration was recorded at 29.85 mg/m³ in the Tikrit site during the spring season, while the lowest concentration was 1.2 mg/m³ in the Abotuama site during the spring. The average temperatures were identical in the three study sites and during the fall, winter and spring seasons, as they were 30.25, 12.5 and 31 ˚C during the three seasons, respectively (Figure 1i).
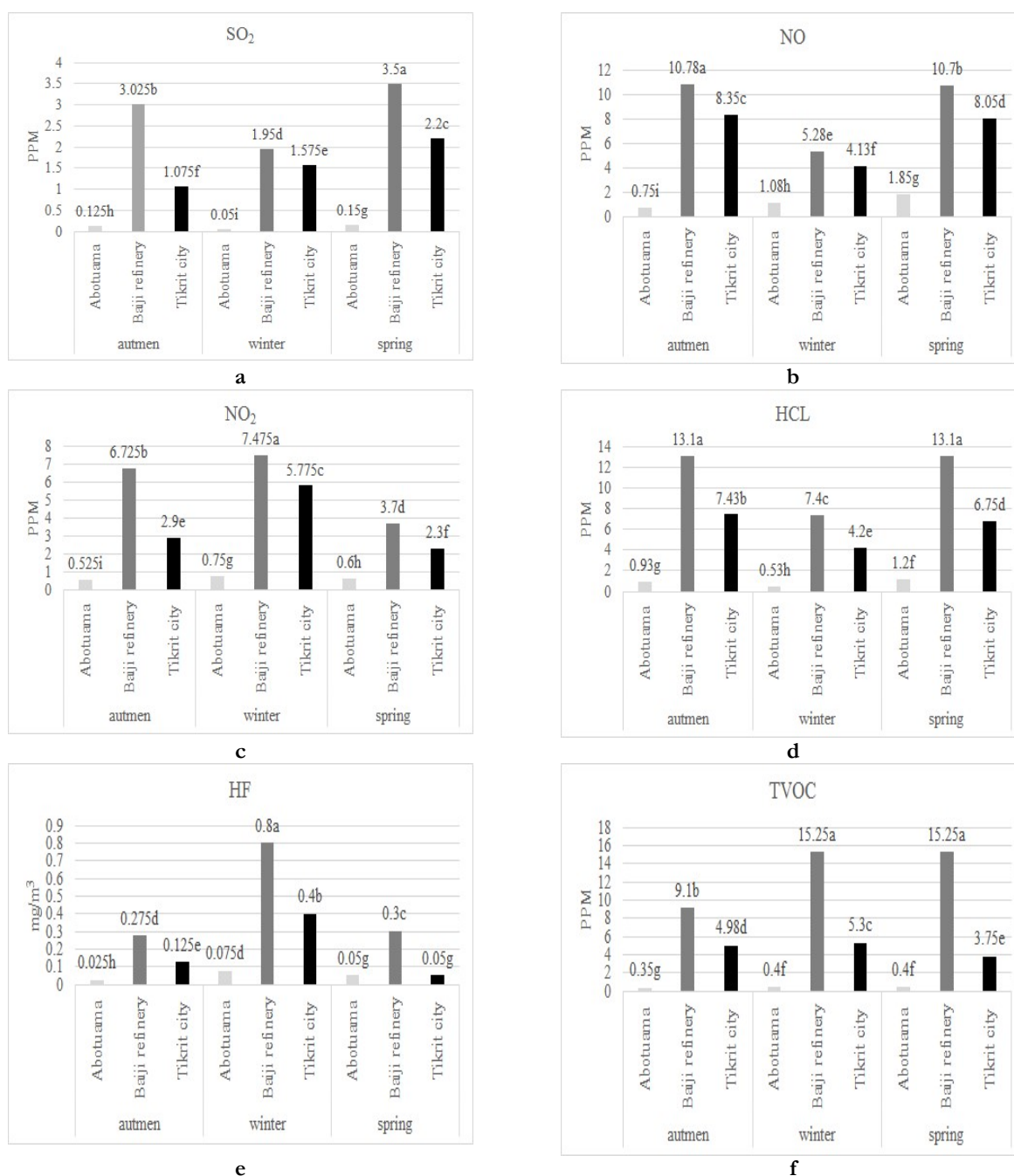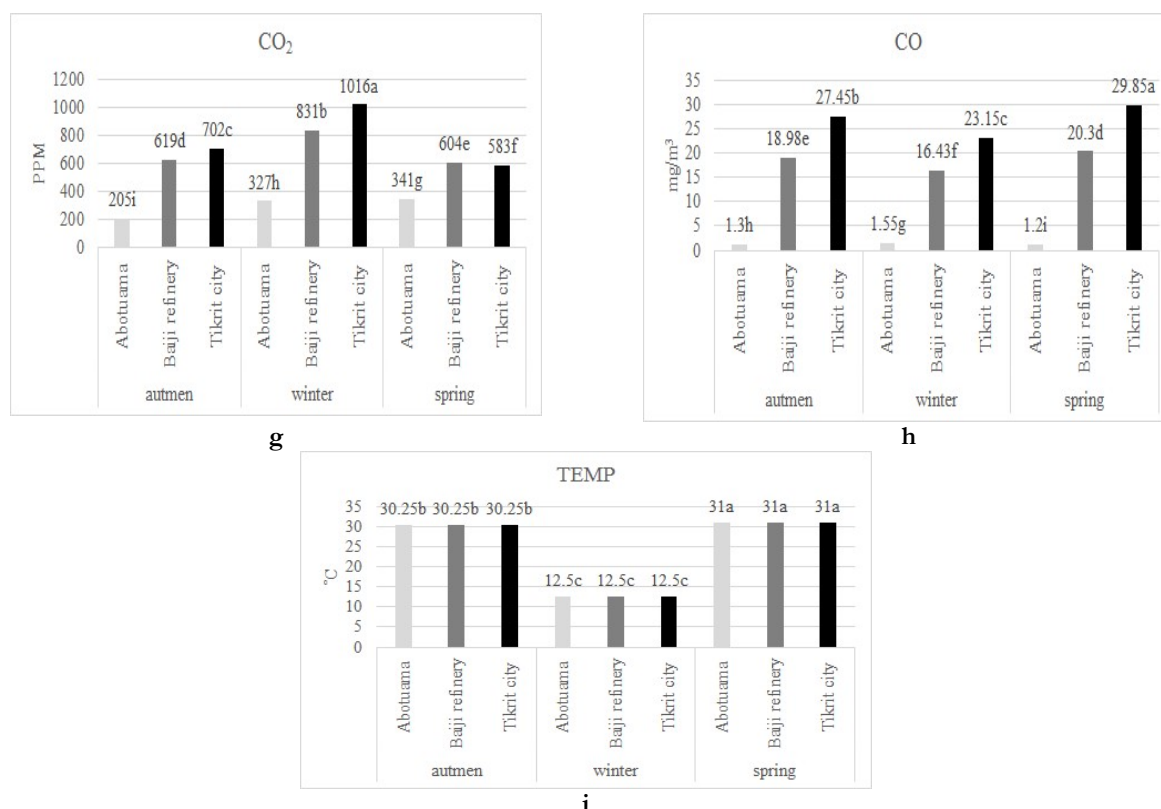
Figure 1. Average air pollutants and temperatures within the study locations and seasons. *Means with the same letter are not significantly different.*
Figura 1. Concentrações medias de poluentes atmosféricos e temperaturas nos locais de estudo e estações do ano. *Médias com a mesma letra não são significativamente diferentes.*

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Continuation of Figure 1. Average air pollutants and temperatures within the study locations and seasons. *Means with the same letter are not significantly different.*
Continuação da Figura 1. Concentrações medias de poluentes atmosféricos e temperaturas nos locais de estudo e estações do ano. *Médias com a mesma letra não são significativamente diferentes.*

It is noted from the results that the concentrations of atmospheric air pollutants increased in the areas of the Baiji refinery and the city of Tikrit, compared to the rural Abotuama area, which is far from pollution sources. means of heating and heavy traffic (especially at the height of the cold season when citizens and students rely more on means of transportation) in the city of Tikrit, as the gases emitted from these and other sources accumulate in the nearby atmosphere, and this leads to an increase in gas concentrations, and it is noted that all gaseous pollutants are the combustion products that were discovered in the studied areas, their sources may include the incineration furnaces of oil installations, electric power stations and other factories.

We note when comparing pollutant rates within the studied sites and seasons with the standards of some international environmental organizations (Table 1), we find that the results we obtained were high for sulfur dioxide and nitrogen oxides, while they were within the safe limits for hydrochloric acid, hydrogen fluoride, TVOC, carbon monoxide and carbon dioxide.

Table 1. Global determinants of some atmospheric air pollutants (TRNKA, 2020).
Tabela 1. Determinantes globais de alguns poluentes atmosféricos (TRNKA, 2020).

Examinations Organizations	SO_2 (ppm)	NO_x (ppm)	HCL (ppm)	HF (mg/m³)	TVOC (ppm)	CO_2 (ppm)	CO (mg/m³)
WHO	–	0.100−0.015	–	1.1	300	30000−5000	35−9
EPA	0.5−0.03	0.53	–	–	50	10000	35−9
MoE	0.1−0.018	0.05−0.04	18	–	–	–	35−10

4. DISCUSSION

The present results are consistent with those of Abass et al. (2016) who studied the concentration of pollutants (VOCs, SO_2, H_2S, NO_2) and evaluated the impact of fuel burning in urban areas in the Nahrawan suburb – of Baghdad city, and found that the value of these gases was changed from one location to another according to the quantity and quality of fuel used and wind direction, and concluded the concentrations of all the gases that were examined in the study area exceeded the standards of the World Health Organization and national standards, while the cause of air pollution in urban areas was attributed to human activities such as movement behavior, waste management, industrial development, production and use of energy (for treatment, heating and cooking), and the activities that result in it. Toamma; Al-Mosuwi (2022) also found, through researching the concentration of atmospheric air pollutants in three regions of Basra Governorate, that hydrocarbon concentrations increased several times more than the national determinants of safe ambient air quality during the research period of 0.24 ppm per 3 hours. He recommended obligating the oil companies operating in the governorate with legislation and laws to reduce the dangerous environmental effects on the health of citizens, as it is the main cause of air pollution and its deterioration in the governorate, and to address the problem of lack of electric

power and develop the necessary solutions to reduce the effects of the huge increase in the number of vehicles, as the exhaust gases that consists of carbon dioxide and water vapor usually accompanied by a small amount of some organic molecules that have not been completely oxidized, in addition to a small amount of toxic carbon monoxide and some nitrogen oxides and formaldehyde gas, and it also contains sulfur dioxide gas found in petroleum during its combustion. Therefore, vehicles contribute a great role in air pollution, especially within Iraqi cities in general, where it was found that the amount of air needed to burn (1 kg) of fuel equals (15 kg) in terms of weight, but in terms of volume, the combustion of one liter of fuel requires 9 tons of air, and the combustion process is ideal if it leads to complete combustion of the fuel, which will produce the two substances (CO_2 and H_2O). In most cases, combustion is incomplete, which leads to air pollution from the emission of toxic components from vehicle exhausts.

4.1 Analysis of the relationship between concentrations of atmospheric air pollutants and seasonal temperatures

All of the statistical analyzes (correlation coefficient, regression coefficient, and coefficient of determination) were conducted as an average for the three study sites because of the similarity of seasonal temperatures during the study period. The results of Table (2) showed that the analysis of Pearson's correlation coefficient (R) for the concentrations of atmospheric air pollutants with seasonal temperatures showed variations in different types of pollutants studied, and it was negative (inverse) highly significant (at a probability level of 1%) for HF with temperature. The value of the correlation coefficient was 0.574. There were positive (direct) and low significant correlations (at a probability level

of 5%) for nitrogen monoxide NO and hydrochloric acid HCL with values of 0.409 and 0.314, respectively. While there were negative and low significant correlations of nitrogen dioxide NO_2 and carbon dioxide CO_2 with seasonal temperature levels with values of -0.355 and -0.418 respectively, the values of the rest of the correlation coefficients for atmospheric air pollutants with temperatures did not reach the statistical significance limits.

The results of Table (2) showed that the values of the regression coefficients β for the effect of temperature levels on atmospheric air pollutants were significant at the concentration of SO_2, TVOC and CO, as the values of the regression coefficients for these variables indicate that each degree of temperature increase lead to increases the concentration of SO_2 and CO by an amount 1.4 ppm and 0.10 mg/m³ for each of them, respectively, while an increase in temperature by one degree leads to a decrease in TVOC concentration by -0.17 ppm, and the rest of the regression coefficients did not reach the limits of statistical significance, and the effect of temperature was direct on NO and HCL concentrations While it had the opposite effect on the concentrations of NO_2, HF, and CO_2.

The values of the determination coefficient (R^2) shown in Table (2) also showed that the contributing effects of seasonal temperatures to the concentrations of the studied atmospheric air pollutants were all significant except for the concentration of SO_2 and CO gases for which the calculated F values were less than the tabular ones. The percentages of the contributing effects of temperature ranged between 1% in the concentration of total volatile organic compounds TVOC and 33% in the concentration of hydrogen fluoride gas HF.

Table 2. Pearson correlation, regression, and determination coefficients between seasonal temperature levels and concentrations of atmospheric air pollutants.
Tabela 2. Correlação de Pearson, regressão e coeficientes de determinação entre níveis sazonais de temperatura e concentrações de poluentes atmosféricos.

Depen. variable	Temperature							
	R	β		T		R^2	F	
Indepen. variables		β0	β1	Calculated	Tabulated		Calculated	Tabulated
SO_2 (ppm)	0.198	22.45	1.4*	0.61	0.53	0.04	0.28	0.61
NO (ppm)	0.409*	19.30	0.93	0.27	1.19	0.17*	1.4	0.27
NO_2 (ppm)	-0.355*	28.67	-1.20	0.35	1.004	0.13*	1.008	0.35
HCL (ppm)	0.314*	21.01	0.59	0.41	0.87	0.10*	0.76	0.41
HF (mg/m³)	-0.574**	29.43	-20.76	0.11	1.85	0.33*	3.43	0.11
TVOC (ppm)	-0.109	25.60	-0.17*	0.78	0.29	0.01*	3.44	0.11
CO_2 (ppm)	-0.418*	33.12	-0.02	0.26	1.22	0.18*	1.48	0.26
CO (mg/m³)	0.124	23.05	0.10*	0.75	0.33	0.02	0.11	0.75

** and * are significant at the 1 and 5% probability level, respectively.
** e * são significativos ao nível de probabilidade de 1 e 5%, respectivamente.

As climate change may alter the health effects of air pollution, there is increasing concern about the effects of temperature changes on the impact of pollutants on mortality (LI et al., 2017). To date, little is known about the potential interaction between air pollution and air temperature. Researchers have previously investigated the role of the season as a modifier of air pollution (ZHAO et al., 2019). The season is clearly related to temperature, and this highlights the need for a comprehensive investigation of the interaction between air pollution and temperature (FENG et al., 2021). The effects of temperature modulation on PM10, SO_2, and O_3 pollutant concentrations have been indicated (LIU et al.,

2017). The results of this study are consistent with those of many previous studies, as some studies reported that the effects of NO_2 air pollutants were more pronounced in the cold season than in the warm season (QIU et al., 2015). NO_2 air pollution may have immediate effects on some specific disease outcomes, such as myocardial infarction (ARGACHA et al., 2016).

DUAN et al. (2019) reported that severe climatic conditions often in the cold season (for example, thunderstorms and heavy rain) can reduce the concentration of pollutants, while NO_2 pollution peaks during winter, and the effect of temperature is stronger below the cold

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threshold, the higher relative effects during the cold season may be due to synergistic effects between air pollution and temperature.

The results of the study of Mohammadi et al. (2019) showed that the levels of NO_2, SO_2, PM10 and PM2.5 in atmospheric air increased when the temperature increased. Conversely, Trinh et al. (2019) confirmed in their study in Mexico over the period 2003-2007 that high variability in temperature inversion intensity occurred from November to May, and in the rainy months from December to March, there were lower average temperatures. High concentrations of PM10, NO_2, NO_x, CO and SO_2 prolong the period of temperature inversion and low humidity.

5. CONCLUSIONS

We conclude from the foregoing that there is a significant effect of the oil industry in the Baiji refinery and the population density of Tikrit city in raising the concentrations of gases polluting the air, especially during the rainy winter months, compared to the rural area (Abotuama) in which the concentrations of toxic gases were at low levels. We also conclude that the concentrations of atmospheric air pollutants SO_2, NO, HCL, and CO increase in the warm and hot seasons, while the concentrations of NO_2, HF, TVOC, and CO_2 pollutants increase during the cold seasons. A series of worldwide epidemiological and observational studies have found independent negative effects of air pollution and air temperature on human health.

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