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Research Paper

Changes in Climate Indices (Ivanov, Barat, and Emberger) Due to Greenhouse Gas Emissions From Gas Flares in Ahvaz Oil Field (2008-2018)

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ABSTRACT

Background & Aims of the Study: Gas condensate flares are a crucial factor in greenhouse gas emissions. The present study aimed to investigate the global warming potential resulting from gas condensate flares in the Ahvaz oil field, Ahvaz City, Iran, and its impact on climate indices from 2008 to 2018.

Materials and Methods: This is a descriptive cross-sectional study. The information on gas flares and climate data has been obtained from the National Iranian South Oil Company (NISOC) and meteorological stations in Khuzestan Province, Iran. The emission factor of greenhouse gases due to the burning of these flares was calculated after obtaining climatic information on gas flares in the study area. The climate indices of Ivanov, Emberger, and Barat were calculated for 11 years. Finally, the relationship between climate indices and Global Warming Potential (GWP) was determined using multiple regression.

Results: The results showed that during the research period, an average of 626831.2.2 tons of carbon dioxide (equivalent) was produced due to gas flares in one month in the Ahvaz oil field. Carbon dioxide was responsible for 90% of the global warming effect of the flares. Based on the results of calculating climate indices, Ahvaz City in the studied years was classified in the category of "semi-arid" in Barat index, "dry desert" in Ivanov index, and "semi-arid desert" and "severe desert" in Emberger index.

Conclusion: The results of correlation analysis between GWP and climate indices show a significant negative correlation between the values of the Emberger index and the global warming potential caused by gas flares, indicating the impact of greenhouse gases on climate change in Ahvaz. These changes have intensified phenomena such as dust and severe floods.

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1. Introduction

Greenhouse gases and global warming are major phenomena worldwide [1]. Greenhouse gases, including carbon dioxide, methane, nitrogen monoxide, carbon chloride, and carbon fluoride in the atmosphere, receive long-wavelength waves emitted from the earth's surface, regulate the earth's climate and the atmosphere and provide a balanced temperature for human life [2]. The industrial activities of countries since the post-industrial revolution have increased the concentration of greenhouse gases in the atmosphere and have gradually led to global warming [3]. Harmful effects of climate change, such as changes in the life cycles of plants and animals, have adverse outcomes for composition, flexibility, the efficiency of natural ecosystems, the function of social and economic systems, and human health [4].

The outcomes of climate change can be classified as direct and indirect (economic) damages. Regarding direct damage, rising temperatures lead to rising sea levels due to the melting glaciers [5]. One of the most important factors in producing greenhouse gases is the oil and gas industry [6]. About 21% of man-made greenhouse gases are attributed to these industries [7]. Flares are also known as the most crucial sources of air pollutants and greenhouse gases in these industries [8]. Industrial flares are units designed to eliminate hydrocarbon and excess gases from chemicals associated with petrochemical units and refineries. A flare is an extended chimney or vertical pipe that is used as an essential component in oil wells, refineries, petrochemical complexes, and chemical plants to burn gases and wastewater and discharge flammable and toxic liquids and can prevent hazards [9]. The most critical compounds in the transfer of gas flow to the flare network include ethane, methane, propane, butane, and hydrogen sulfide. When these gases are burned in the flare network, pollutants such as nitrogen oxides, carbon monoxide, carbon dioxide, sulfur oxides, and other pollutants are released into the environment [10]. Releasing these pollutants into the environment seems to be an important factor in air pollution and the greenhouse effect [11].

Assuming complete combustion, the products of combustion of the flare gas will be SO_2, CO_2, NO_x, and some hydrocarbons [12]. In the case of incomplete combustion, carbon monoxide is one of the output products [13]. Carbon dioxide, carbon monoxide, and nitrous oxide are greenhouse gases [14]. The Global Warming Potential (GWP) for the major emitted gases, including carbon monoxide, carbon dioxide, methane, nitrogen oxides, and ozone, can be calculated [15]. For this purpose, we can use the coefficients of the effect of each greenhouse gas and its conversion to relative proportions of carbon dioxide [16].

Ahwaz oil field is an oil-rich region with many oil facilities, and there are many gas flares in this area [17]. The results of various studies have shown that this city is the most polluted city in Iran [18, 19] and the major source of this pollution is the oil and gas industry [20]. According to the World Bank statistics released in 2016, about 154 billion cubic meters of gas are burned annually from flares worldwide. This figure is equivalent to 5% of world natural gas production, 25% of gas consumption in the United States, 30% of gas consumption in the European Union, and 75% of gas exports. The energy obtained from burning this amount of gas is equivalent to 4.2 million barrels of crude oil per day. In Africa, over 35 billion cubic meters of gas are burned annually by flares, which is equal to half the continent's energy consumption [21]. Various studies have shown that greenhouse gases are the most critical cause of global warming. Various studies have been conducted on the role of greenhouse gases in the oil industry with global warming.

Bach [22], in a descriptive study, studied the role of public oil industries in global warming. Also, Franta [23] described oil activities as the greatest human impact on global warming. Climate change is one of the tangible events in today's world [24]. One of the methods of calculating climate change is the study of climate indices in different periods in a region [25]. Various climate indices have been proposed, including the methods of De Martone, Ivanov, Barat, Koppen, and Emberger [26]. To calculate climate indices, different components are needed, such as precipitation, temperature, relative humidity, and evaporation [27]. The role of greenhouse gases in climate change can be understood by examining the amount of greenhouse gas emissions and the global warming coefficient resulting from them, as well as by examining climate indices in a region. After calculating the emission factor of greenhouse gases from gas flares in the Ahvaz oil field, the climate indices of Emberger, Ivanov, and Barat were calculated for 11 years, and the relationship between them was studied.

2. Materials and Methods

A descriptive-analytical study was conducted to determine the share of oil flares in the Ahvaz oil field in greenhouse gas emissions and climate change. Therefore, in

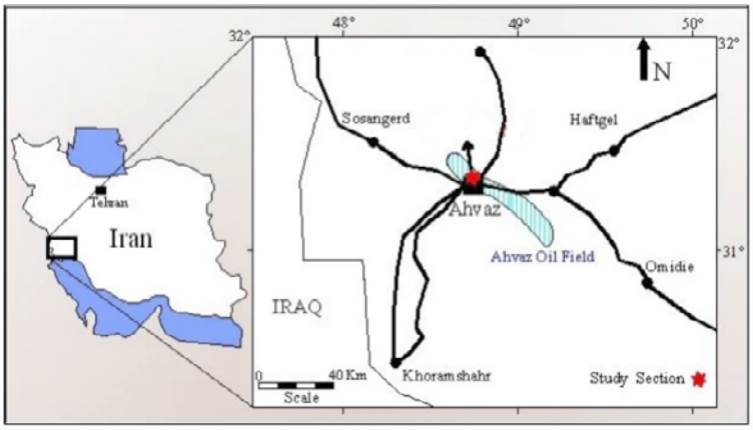

Figure 1. Study area (Ahvaz oil field)

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addition to calculating the emission factor of greenhouse gases from the flares in the Ahvaz oil field, the climate indices of Ivanov, Barat, and Emberger should be calculated. Necessary information, including the number of active flares in the study area and the amount of condensate burned in each, was obtained from the National Company of Southern Oil Fields. Climatic information, such as average, minimum, and maximum temperature, relative humidity, evaporation coefficient, annual rainfall, surface runoff coefficient, and the number of rainy days, were obtained from the meteorological organization. Figure 1 shows the study area, which is an oil-rich region in southwestern Iran (Ahvaz City).

Emission coefficients of greenhouse gases (carbon monoxide, carbon dioxide, methane, and N_2O) caused by condensate flares were calculated using the DCCEE1 2009 method [28]. To determine the emission coefficients of greenhouse gases from flares, the following process has been performed:

• Determining the amount of gas condensate entering each flare

• Converting mass to volume: At this stage, mass discharge was converted to volume because the purpose is to determine the amount of greenhouse gas emissions. For this purpose, Equation 1 was used:

$$1.\ \frac{mg}{m^2}=\frac{ppm\times M}{24.45}$$

, where:

M is the molecular weight.

ppm is the contaminant concentration per volumetric unit.

$\frac{mg}{m^2}$ is the mass concentration of pollutants per unit mass.

Table 1 presents the molecular weight of each of the pollutants studied.

After converting the mass unit to a volumetric unit and considering the molecular weight, the emission factor of each greenhouse gas (N_2O, CH_4, CO, CO_2) was calculated based on Equation 2:

$$2.\ E=Q\times C$$

, where:

E=Pollutant emission rate (kg per time unit)

Q=Inlet gas condensate (cubic meters per time unit)

C=Concentration of each greenhouse gas per cubic meter of gas condensate (kg per time unit)

Then, the global warming potential due to the emission of greenhouse gases caused by the flares in the Ahvaz oil field was calculated over 11 years. Data were analyzed in time series. Greenhouse gases of carbon dioxide and nitrous oxide are produced and emitted by fuel combustion. Assuming complete combustion, the equation and products resulting from the combustion of hydrocarbons can be shown by Equation 3.

$$3.\ C_xH_yO_z+(X+\frac{Y}{4}-\frac{Z}{2})O_2(X)CO_2+(\frac{Z}{2})H_2O$$

The release of carbon dioxide is due to the oxidation of hydrocarbons during the combustion process. Almost all the carbon in the fuel is converted to carbon dioxide during the combustion process, which is independent of the fuel and the type of combustion. Also, methane emissions may be due to incomplete fuel combustion and unburned methane. Additionally, nitrous oxide gas is produced and released during a series of complex re-

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Table 1. Volumetric concentration measurements of each greenhouse gase [29]

Component	CO (g/mol)	CO_2 (g/mol)	N_2O (g/mol)	SO_2 (g/mol)
Molecular weight	28	44	44	64

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actions during the combustion process. Unlike carbon dioxide, the emission of methane and nitrous oxide depends on the type of fuel and the type of combustion. The emission of methane and nitrous oxide (based on the equivalent of carbon dioxide) in combustion sources is significantly less than the emission of carbon dioxide. Each of the four greenhouse gases has an impact coefficient on global warming. This coefficient is 1 for carbon dioxide, 1.9 for carbon monoxide, 25 for methane, and 298 for nitrous oxide [30]. Therefore, by calculating the emission factor of greenhouse gases and multiplying the calculated values by the impact coefficient of global warming, the total global warming potential caused by gas condensate flares is calculated.

Calculation of climatic indices

A: Emberger climate index

The calculation of the Emberger coefficient (Q_2) is based on Equation 4:

$$4.\ Q_2 = \frac{2000P}{M^2-m^2}$$

, where:

P is the average annual rainfall per millimeter.

M is the average maximum temperature in the hottest month of the year in terms of Kelvin.

m is the average minimum temperature in the coldest month of the year in terms of Kelvin.

Finally, the climatic index is determined in the Emberger index based on Figure 2 [31].

B: Ivanov climate index

To calculate the climate in the Ivanov index, we need humidity, evaporation, and temperature indices. Ivanov index is described in Equation 5:

$$5.\ I = \frac{H}{\sum Em}$$

, where:

I=Ivanov climate index

H=Average annual relative humidity

ΣEm=Annual evaporation rate

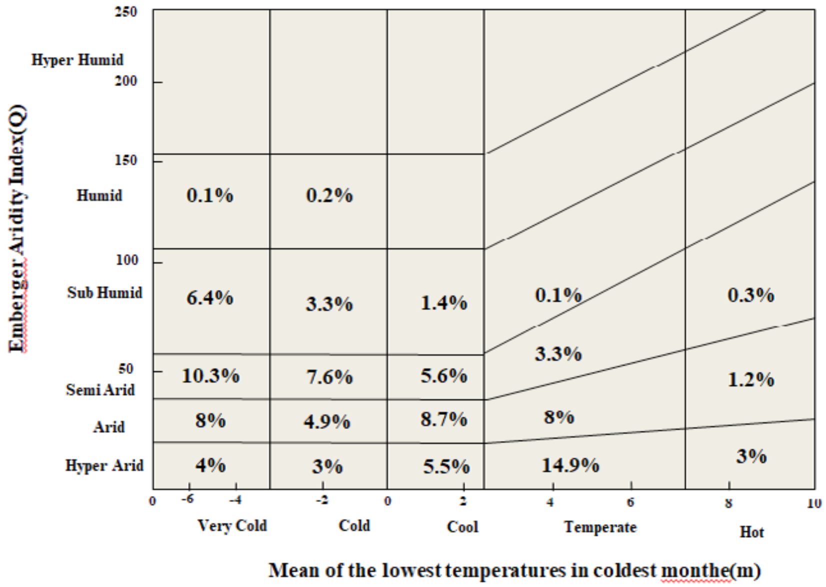

Figure 2. Emberger climate diagram

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Table 2. Classification of Ivanov index based on climate type

Climate Type	Ivanov Humidity Coefficient Range
Very humid and forested	I ≥1.5
Humid and forested	1≤ I ≤1.49
Steppe and forested	0.6≤ I ≤0.99
Steppe	0.3≤ I ≤0.59
Desert	0.13≤ I ≤0.29
Dry desert	0≤ I ≤0.12

To calculate the annual evaporation rate, we calculated total evaporation in all the months of the year. To calculate the annual evaporation, Equation 6 is used:

6. $E_m=0.00018(2.5+t^2)(100–RH)$

, where:

E_m=Evaporation rate in each month of a year (in centimeters)

t=Average monthly temperature (in terms of Celsius)

RH=Average monthly temperature (in terms of Celsius)

The Ivanov index classification is presented in Table 2 [32].

C: Calculating the Barat index

In this method, the climatic coefficient of Barat, which depends on rainfall, surface runoff, and annual rainfall, is calculated using Equation 7:

7) $I=\frac{P(1-C)}{365-N}-\frac{E}{365}$

, where:

I=Barat climate index

P=Average annual rainfall (in millimeters)

N=The number of rainy days per year

E=Annual evaporation (in millimeters)

C=Surface runoff coefficient

The calculation of the surface runoff coefficient is also based on Equation 8:

8) $C=\frac{R}{P}$

, where:

R is the runoff (in millimeters). Table 3 presents the classification of the Barat index [33].

Finally, the relationship between the calculated index levels and the GWP coefficient is investigated via linear regression.

3. Results

The information about the flares in the studied units was determined using the field method and by attending

Table 3. Classification of Barat index based on climate type

Climate Type	Barat Coefficient Range
Desert	I <-20
Semi-arid	-20≤ I <0
Semi-humid	0≤ I <7
Humid and forested	I ≥7

Table 4. Calculation of Global Warming Potential (GWP) in Ahvaz oil field per month

Greenhouse Component	Emission (1000 kg Per Month)	Equivalent kg CO_2 kg	Normalization Indices	Weight Indices	Total of Global Warming Potential Ton CO_2 e/FU
CO_2	565210	1	4.41 ($kg\ CO_2 - Eq$)	0.2	565210
N_2O	171.80	298		58.6	51196.4
CO	37.98	1.9		0.38	72.162
CH4	414.1	25		5	10352.5
Total	582842.1	-	Sum of GWP	1	626831.2

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the National Company for Oil Fields and examining the available documents. The information is as follows:

There are 20 units with gas flares; 53 gas condensate flares were identified. The height of flares is from 4 to 68 meters. The diameter of flares is 4 to 30 inches. Structures are mostly made of stainless steel and steel. The flares contain natural gas, sour gas, operating gas, hydrocarbons, methane-ethane-propane, and butane. To calculate the amount of greenhouse gas emissions, the standard method of converting fuel to pollutants provided by the Department of Climate Change and Energy Efficiency (DCCEE) (2009) was used. For this purpose, the type of fuel in the flare and its monthly amount are considered input, and the output includes the amount of emitted greenhouse gases. The calculated values are in units of mass (tons), which is needed to convert the unit from volume to mass. To calculate the GWP factor per unit, the values of greenhouse gases specified in the weighting index are multiplied, and the final capacity of GWP for all greenhouse gases is added. These values are determined per month (Table 4).

The results showed that a total of 626831.2.2 tons of carbon dioxide was produced due to the activity of gas flares in one month in the Ahvaz oil field. The results showed that a total of 626831.2.2 tons of carbon dioxide (equivalent) was emitted due to the activity of gas flares in one month in the Ahvaz oil field. The highest amount of greenhouse gas emissions are related to the Mansouri desalination plant with 217714.76 tons, and the lowest to the Mansouri gas pressure station and the Mansouri operation with 2 tons of carbon dioxide (equivalent) per month. The highest greenhouse effect is related to carbon dioxide emissions of 565210 tons per month. Given the long shelf life of carbon dioxide in the atmosphere, 80% of which is absorbed by the oceans for 2 to 200 years and 20% remains in the atmosphere for thousands of years, this volume of greenhouse gases released in the atmosphere can have consequences such as rising average temperatures and climate changes. Figure 3 compares the emission factor of greenhouse gases due to the activity of gas flares in the Ahvaz oil field. These results show that 90%, 8%, and 2% of the global warming effect is produced by CO_2, N_2O, and methane, respectively,

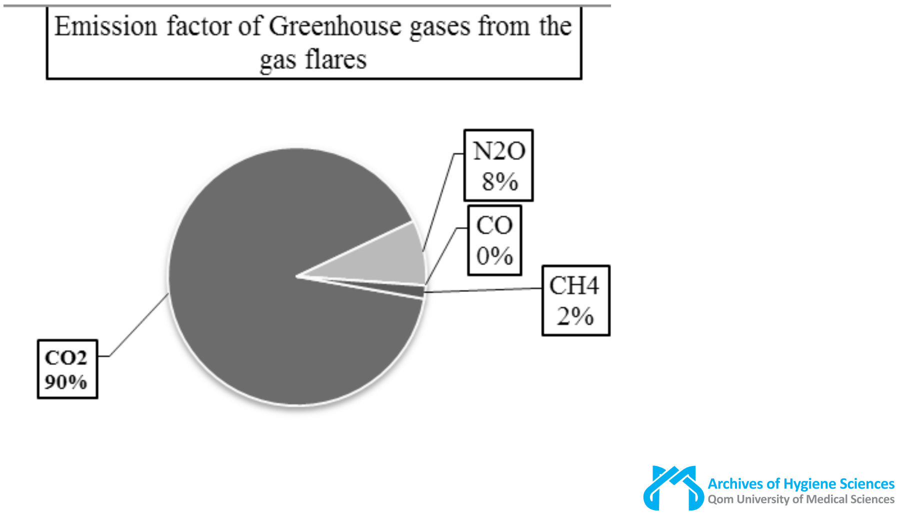

Figure 3. Comparison of greenhouse gas emission factors due to the activity of gas flares in Ahvaz oil field

Table 5. Climate information of Ahvaz oil field (2008-2018)

Year	Relative Humidity(%)	Evaporation (mm/y)	Min T (C^0)	Max T(C^0)	Raining (mm/y)
2008	47.4	1996	13.68	40.31	155.6
2009	48.3	2065	13.87	40.52	222.4
2010	47.1	2118	14.04	40.28	173.4
2011	47.6	1983	14.5	39.96	273.8
2012	46.6	2006	14.61	40.81	198.5
2013	47.3	1976	14.17	40.94	215.1
2014	47.8	2126	14.65	41.02	161.5
2015	48.5	2067	14.29	40.78	269.7
2016	46.9	2105	13.96	39.63	197.8
2017	47.5	1998	14.74	41.73	230.1
2018	49.3	1779	14.54	39.33	389.4

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that are produced by the activity of the flares. The effect of carbon monoxide was less than 1%. The assumption in these calculations is that the inlet material of gas flares is completely burned.

To determine the climate index, climate data and greenhouse gas emissions must be available as time series data. Table 5 lists the mean values of climate data used in the research.

Figure 4 shows the ambrotromic curve (temperature and precipitation) from 2008 to 2018. This diagram shows that the dry season in Ahvaz has been 8 to 9 months per year on average. This period lasts from mid-February to mid-October.

Table 6 presents the results of calculating the GWP coefficient and climate indices of Ivanov, Barat, and Emberger from 2008 to 2018.

Based on these results, in the Barat index, Ahvaz City is in the category of "semi-arid" climate in all the years studied, and according to the Ivanov index, it is in the category of "dry desert. " Also, according to the Emberger index, for 2015 and 2018, when the region's climate was in the "semi-arid desert" category, in other years, the climate index was in the "severe desert" category.

The best climate indices of Barratt, Ivanov, and Emberger in 2018 are -3.16, 0.105, and 48.52, respectively, and the worst climate indices of 2008 are -8.21, 0.044,

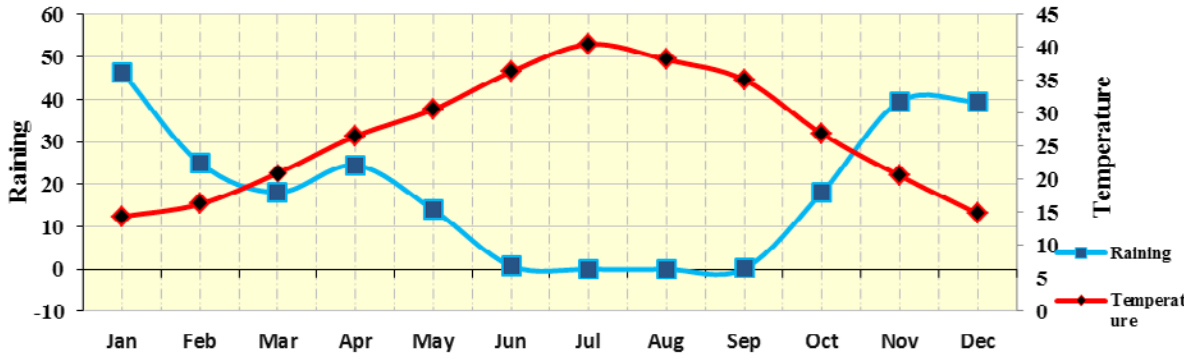

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Figure 4. Ambrotromic curve for average temperature and precipitation in Ahvaz oil field (2008-2018)

Table 6. Calculation of climate indicators in Ahvaz oil field (2008-2018)

Year	Emberger		Ivanov		Barat		GWP
	Index	Description	Index	Description	Index	Description	Ton CO_2 e/FU
2008	17.95	Severe desert	0.044	Dry desert	-8.21	Semi-arid	7132153
2009	25.52	Severe desert	0.062	Dry desert	-6.83	Semi-arid	7281259
2010	20.27	Severe desert	0.049	Dry desert	-8.03	Semi-arid	7065327
2011	32.91	Severe desert	0.076	Dry desert	-5.48	Semi-arid	7559901
2012	22.78	Severe desert	0.055	Dry desert	-7.54	Semi-arid	7421974
2013	24.28	Severe desert	0.06	Dry desert	-7.15	Semi-arid	7455412
2014	18.44	Severe desert	0.045	Dry desert	-8.18	Semi-arid	7268036
2015	30.8	Semi-arid desert	0.077	Dry desert	-5.27	Semi-arid	7512568
2016	23.85	Severe desert	0.056	Dry desert	-5.36	Semi-arid	7403862
2017	25.14	Severe desert	0.065	Dry desert	-6.53	Semi-arid	7457102
2018	48.52	Semi-arid desert	0.105	Dry desert	-3.16	Semi-arid	7859843

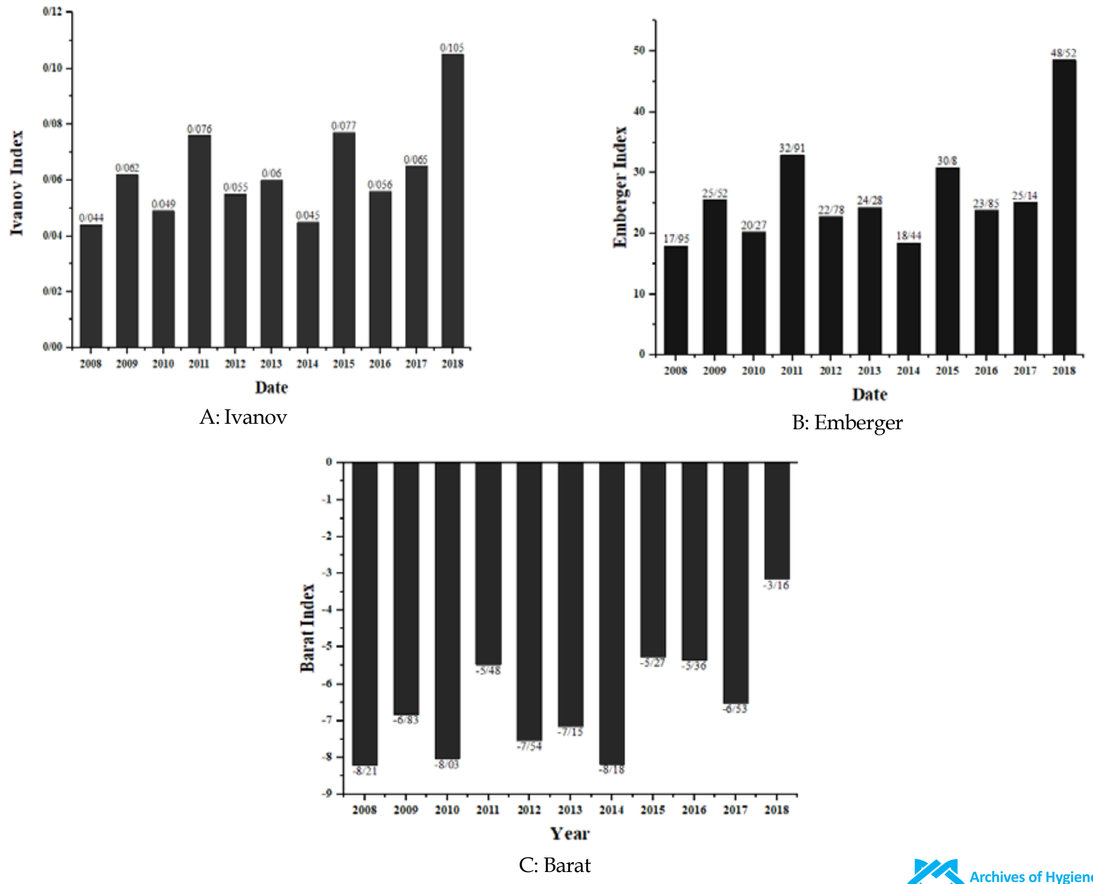

Figure 5. Comparison of the trend of calculated values of climate indices in Ahvaz oil field (2008-2018)

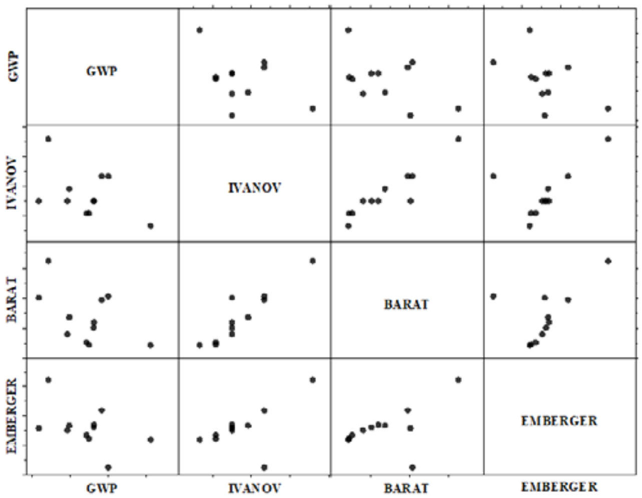

Figure 6. Multiple regression results between studied climatic indices and GWP coefficient

and 17.96, respectively. Figure 5 compares the trend of the calculated values of climate indices.

A correlation test was used to analyze the relationship between climate indices and GWP calculated due to the emission of greenhouse gases from gas flares in the study area. The results showed a significant correlation between the values of the Emberger climate index and the global warming potential caused by gas flares ($P<0.05$), but no significant correlation was observed between GWP and Ivanov and Barat indices. The correlations are negative, i.e., with the increase in the GWP coefficient and global warming in this period, climatic indices improve. Table 7 lists the correlation coefficient between climate indices and the GWP coefficient from 2008 to 2018 in the Ahvaz oil field, and Figure 6 shows the multiple regression relationship between the studied climate indices and the GWP coefficient.

4. Discussion

Climate change and global warming in recent decades have had major effects, such as floods, severe storms, and intensification of aerosol. In recent decades, Ahvaz has increasingly faced these phenomena, including dust storms. Achakulwisut et al. identified climate change and an increase in drought as the most crucial contributors to the aerosol increase in the southern United States [34]. Although various factors contribute to global warming, greenhouse gases are important in this phenomenon [35]. Undoubtedly, oil-rich areas with numerous industrial facilities are more exposed to the effects of this phenomenon than other areas. Ahvaz has the largest oil field in Iran. The highest concentration of oil facilities and gas flares is in this area. The findings showed that assuming the complete combustion of gas of flares, approximately 7401585 tons of carbon dioxide enters Ahvaz's atmosphere annually. Considering the climatic situation of this area (semi-arid class in Barat index, desert in Ivanov index, and semi-arid and extreme hot desert in Emberger index), the entry of this amount of greenhouse gases significantly affects the climate in the long run. The results of the present study confirmed a negative correlation between climate indices and GWP in the study period from 2008 to 2018. Willington et al. [36] and Ward [37] have examined this issue in several studies.

Sangsaraki and Anajafi described energy recovery from the burning of gas condensate flares as an ideal solution to reduce its environmental impact [38]. These climate indices are often climatic components and cannot be used as objective criteria for estimating climate change. The

Table 7. Correlation coefficient between climate indices and GWP coefficient during 2008-2018 in Ahvaz oil field (N=11)

GWP	Ivanov	Barat	Emberger
The Pearson correlation	-0.659	-0.700	-0.890*
Sig. (2-tailed)	0.079	0.057	0.036

*. Correlation is significant at the 0.05 level (2-tailed).

long-term persistence of greenhouse gases such as carbon dioxide, 80% of which remain in the atmosphere for more than 100 years, shows the undeniable effect of gas condensate burners on long-term climate change requiring stronger management planning to reduce its effects.

5. Conclusion

The results of the present study are based on the daily extraction of an average of 2.7 million barrels of oil from the Ahvaz oil field during 2008-2018, and with the increase in crude oil extraction, the amount of greenhouse gas emissions will also increase. Knowing the status of greenhouse gas emissions from flare activity provides a good opportunity for environmental decisions. The results of the current study show that the effects of burning flares, especially greenhouse gas emissions in southwestern Iran, are significant and demonstrate the need to review and implement plans to prevent combustion, including reducing the input of flares or exploiting it for factors such as energy production.

Ethical Considerations

Compliance with ethical guidelines

The ethical issues have been completely observed by the authors, including plagiarism, informed consent, misconduct, data fabrication and or falsification, double publication and or submission, and redundancy.

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Authors' contributions

All authors equally contributed in preparing this article

Conflict of interest

The authors declared no conflict of interest regarding the publication of this manuscript.

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